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AICE SURVEY OF USSR AIR POLLUTION LITERATURE. VOLUME XXI. ATMOSPHERIC POLLUTANTS IN RELATION TO METEOROLOGICAL CONDITIONS: A PROCEDURE FOR CALCULATING THE ATMOSPHERIC DISPERSAL OF POLLUTANTS AND THE FEASIBILITY OF THEIR STUDY BY MEANS OF SATELLITES

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Volume XXI

ATMOSPHERIC POLLUTANTS IN RELATION TO METEOROLOGICAL CONDITIONS; A PROCEDURE FOR CALCULATING THE ATMOSPHERIC DISPERSAL OF POLLUTANTS AND THE FEASIBILITY OF THEIR STUDY BY MEANS OF SATELLITES

Edited By

M. Y. Nuttonson

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Seven translated Russian papers are presented. Most of these deal with some atmospheric and weather conditions as factors in the dispersal of air pollutants in industrial regions of the USSR. One paper deals with the feasibility of utilizing satellites for the study of atmospheric pollution. Another paper deals with the pollution of the ground layer of the atmosphere. This investigation was conducted on the basis of data on an occurrence of large-scale mild poisoning of people with sulfur dioxide and with products of its oxidation in a given area, as a result of unfavorable meteorological conditions. The paper discusses patterns of dispersal of impurities in the atmosphere as a function of meteorological conditions and gives various formulas for calculating the height of smokestacks, and the dispersal and range of propagation of pollutants. The remainder of the papers deal with the following aspects: characteristics of the meteorological and aerosynoptic conditions of smoke pollution in Novosibirsk; Data on the chemical composition of: atmospheric aerosols of Central Asia, of cloud water in urban industrial districts, and of atmospheric precipitation of the city of Perm; Instructions for calculating the atmospheric dispersal of noxious substances present in industrial emissions.

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PREFACE

The Russian papers translated in this volume relate to several aspects of atmospheric pollution which have been studied in the Soviet Union. Contamination of the natural environment constitutes a major problem in all industrial regions of the USSR. The country's industry and transport are continually bringing about massive qualitative changes in the habitat of man and vegetation through an ever-increasing pollution of air, soil, and streams. Pollution and the need to control it have become a matter of great concern among Soviet conservationists and scientists and they, like their colleagues in the West, have been warning their government of the colossal and sometimes irreparable damage that is being done to the environment and urging that serious and effective steps be taken to avert it.

In the Soviet Union, like in the West, pollution now poses for the leaders of the country some fundamental choices between the economics of production, on one hand, and the progressively worsening living conditions, on the other. There appears to be, at present, a greater appreciation and a better understanding of the immense problems of air and water pollution on the part of the urban and rural administrative agencies. As a result of a mounting demand for the maintenance of a high quality physical environment, protective measures against the pollution threat are gradually taking shape in the USSR and much relevant air pollution research data are being developed in the various industrial regions of that country.

Studies of atmospheric diffusion and air pollution constitute a rapidly developing area of meteorological sciences in the USSR. Determination and analysis of the complex set of meteorological factors causing the processes of atmospheric diffusion are being extensively developed there in conjunction with theoretical and experimental studies of the pattern of propagation and distribution of contaminants in the atmosphere.

Most of the material brought together in this volume deals with some atmospheric and weather conditions as factors in the dispersal of air pollutants in a number of the industrial regions of the USSR, regions that are geographically far apart from each other and subject to different natural and man-made environmental conditions.

The first paper in this volume deals with a report concerning the feasibility of utilizing satellites for the study of atmospheric pollution. This material presents a review of investigations endeavoring to determine gas pollution components in the atmosphere from data on special measurements of outgoing heat radiation.

One report in this volume deals with the pollution of the ground layer of the atmosphere. This investigation was conducted on the basis of data on an occurrence of large-scale mild poisoning of people with sulphur dioxide and with products of its oxidation in a given area of the USSR, as a result of unfavorable meteorological conditions, i.e., under conditions of temperature inversion and consequent accumulation of pollutants in the ground layer of the atmosphere. The report of this investigation discusses patterns of dispersal of impurities in the atmosphere as a function of meteorological conditions and gives various formulas for calculating the height of smokestacks, and the dispersal and range of propagation of pollutants. The volume presents an account of investigations of natural aerosols, with the analysis of their samples collected both under surface conditions and in an airplane during horizontal flights of 300 and 1000 meters above a given area. Other material in this volume deals with the composition of atmospheric water, including precipitation and cloud water, with a comparison of the chemical composition of the frontal clouds in different regions of the Soviet Union, with the mineralization of precipitation, and with the difference between the chemical composition of atmospheric precipitation and that of the cloud water.

Another report included in this volume presents a procedure for calculating the atmospheric dispersal of noxious substances (dust and sulfur dioxide) discharged into the atmosphere by industrial facilities and boiler houses. It examines cases of isolated and of collective sources of discharge of noxious substances, and emphasizes the necessity of taking into account the background pollution of the air reservoir of residential areas in the determination of boundaries of the sanitary-protective zone. It also makes recommendations for implementing basic steps to protect the air reservoir from pollution during the operation of industrial facilities and boiler houses.

It is hoped that the papers selected for presentation in this volume will be conducive to a better appreciation of some of the air pollution investigations conducted in the USSR. As the editor of this volume I wish to thank my co-workers in the Air Pollution Section of the Institute for their valuable assistance.

M. Y. Nuttonson

February 1973

POSSIBILITY OF STUDYING ATMOSPHERIC POLLUTANTS BY MEANS OF SATELLITES

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From Glavnoe Upravlenie Gidrometeorologicheskoy Sluzhby Pri Sovete Menestrov SSSR. "Meteorologiya i Gidrologiya", No. 9. Moskovskoe Otdelenie Gidrometeoizdata. Moskva, p. 3-9, (September 1970).

The article offers a survey of studies dealing with the possibility of determining the content of polluting gaseous components (sulfur dioxide, carbon monoxide, etc.), based on data of spectral measurements of outgoing heat radiation. The available data indicate the fundamental possibility of solving this problem. The necessity of a comprehensive approach to the solution of this problem is discussed and its close relationship to the problem of thermal sounding of the atmosphere from satellites is noted.

Despite the serious steps taken toward reducing industrial pollutants in the atmosphere, the problem of pollutants that sometimes reach dangerous proportions (particularly near industrial centers) is becoming increasingly serious. It has been found, for example, that in many towns the meteorological regime is already substantially dependent on air pollution [1, 7]. The aftereffects of pollution may be even more serious in character. This applies particularly to a number of western European countries.

As an illustration of the validity of this conclusion, Fig. 1 shows data on the increase in the number of automobile engines and the growth in the consumption of electric power and mineral oils as compared with the population increase in the German Federal Republic [7]. It is evident that a linear population growth is accompanied by an exponential increase of the factors determining the atmospheric pollution.

The rapid development of all types of transportation (primarily automotive and air) as well as a vigorous industrial growth raise the level of atmospheric pollution not only in the immediate vicinity of major industrial centers, but also over much larger areas. The pollutants produced by high-flying jet airplanes and those arising from launchings of satellites extend to high layers of the atmosphere [6]. All of this renders the problem of pollutants truly global in scale and makes it necessary to look for possible applications of satellite methods to the study of atmospheric pollutants.

As far as the study of the dust pollution of the atmosphere at various heights is concerned, spectrophotometric observations of the twilight aureole of the earth from manned orbital stations may be of major importance in this case [4]. However, we shall confine our attention only to the discussion of the problem of gaseous components of atmospheric pollutants.

Atmospheric pollutants involve the presence in the atmosphere of both primary polluting components and secondary products arising from various chemical and photochemical reactions. Among the chief components of pollution are compounds of sulfur (mainly SO_2), nitrogen (NO, NO_2 and NH_3), carbon (CO, CO_2), halogens, hydrocarbon compounds, aldehydes and particles (solid aerosols). The most typical components of industrial pollutants are CO, SO_2, NO_2 and O_3. Table 1 gives comparative data characterizing the approximate concentrations of polluting components in a pure and a polluted atmosphere [7]. In all cases except the one involving aerosol pollution, the values of the volume concentration are expressed in ten thousand parts of one percent (ppm).

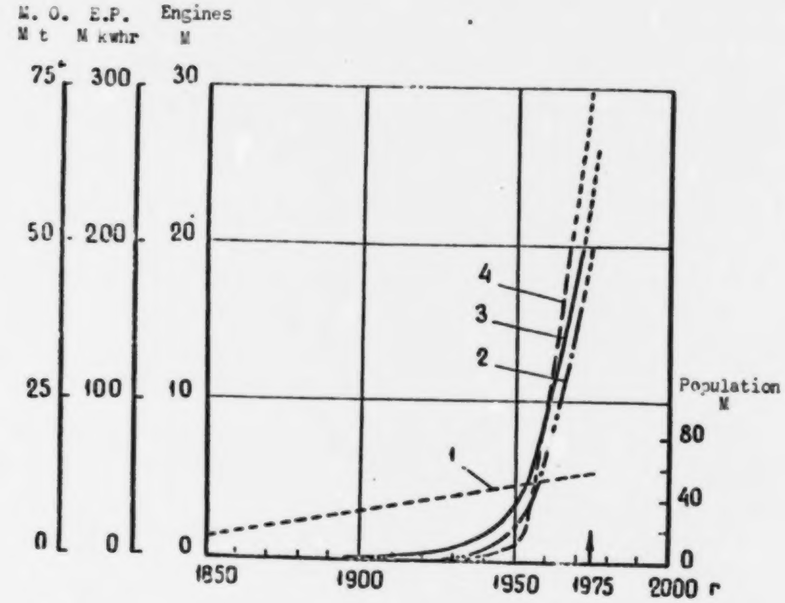

Fig. 1. Growth in the consumption of electric power and mineral oils in the German Federal Republic in comparison with the population increase.
1 - size of population; 2 - number of automobile engines;
3 - consumption of electric power; 4 - consumption of mineral oils.

It is evident that the carbon monoxide concentration exceeds the total concentration of all the other components (with the exception of carbon dioxide). In second place (in importance as a polluting component) should be placed sulfur dioxide and hydrocarbon compounds. Major industrial centers are characterized by the presence of a "coupola" of pollutants over them, the height of which may reach 1000 m and usually exceeds 500 m [7].

One can visualize the various fundamental possibilities of observation and determination of the concentration of polluting components of the atmosphere from satellites. One possible method, for example, is absorption spectroscopy, in which the spectrum of the absorption of solar radiation by the atmosphere during sunrises and sunsets is recorded relative to the satellite, when the sun's rays traverse the thickness of the atmosphere [2]. Obviously, however, this method is not applicable to the lower layers of the atmosphere, where the attenuation of radiation is too great, and thus the signal measured is practically equal to zero. However, the study of the lower layers of the atmosphere is precisely of the greatest interest.

Table 1

Concentration of Polluting Components in a Pure and a Polluted Atmosphere.

Polluting Component	Pure Atmosphere	Polluted Atmosphere
Sulfur dioxide	10^{-3}–10^{-2}	0,02–2
Carbon monoxide	<1	5–200
Carbon dioxide	310–330	350–700
Nitrogen oxides	10^{-3}–10^{-2}	10^{-2}–10^{-1}
Hydrocarbon compounds	<1	1–20
Aerosol pollutants, mg/m^3.	0,01–0,02	0,07–0,7

If the measurements of solar radiation reflected and scattered by the earth are made in the ultraviolet or visible regions of the spectrum, an attempt may be made to use the presence of spectral characteristics of outgoing shortwave radiation which are due to the existence of absorption bands in a number of the polluting components (primarily SO_2, NO_2 and O_3). The practical application of such a method is substantially complicated, however, by the fact that these spectral characteristics are relatively slight, whereas factors interfering with the interpretation of the data such as reflection from the earth's surface and scattering (as well as absorption) by solid aerosols are highly variable and substantial in their influence on the field of outgoing radiation. This situation is aggravated even further by the fact that the above-enumerated gases have absorption bands chiefly in the ultraviolet and visible regions of the spectrum (300-655 nm), where the influence of factors complicating the interpretation of observational data is the strongest.

Certain prospects may possibly be offered by the interpretation of measurement data in the ultraviolet and visible regions of the spectrum, obtainable by using the "correlation" method [6]. This method involves the use of a "correlation" spectrometer, in which the spectrum of outgoing radiation being measured is "modulated" by a given reference spectrum. The similarity of the two spectra appears in the beats of the output signal. The amplitude of this signal serves as the quantitative characteristic of the content of the component being determined in the atmosphere. Airborne tests of such a method for the purpose of determining the content of sulfur dioxide (from data of measurements near the wavelength of 3150 Å) have given encouraging results.

As was conclusively demonstrated by the development of satellite meteorology, most promising for the solution of problems involved in the study of the composition and structure of the atmosphere is the use of data on spectral measurements of outgoing heat radiation [3]. It can be readily ascertained that this conclusion also applies to the solution of the problem of determining the content of atmospheric pollutants. This will be shown by using some results of recent studies [8].

Ludwig, Bartle and Griggs [8] carried out numerical experiments to evaluate the influence on the outgoing radiation of the presence of a layer of polluting component (near the earth's surface) 300 m thick for the following models of stratification of the atmosphere: standard atmosphere ARDC-1959 and arctic winter and tropical atmospheres. Table 2 shows the results of calculations for the 4.6 μm band of carbon monoxide at CO concentrations corresponding to conditions of negligible (1 ppm), moderate (10 ppm) and very heavy pollution (100 ppm). The relative emissivity of the earth's surface was taken as 0.95. The calculations were carried out for different

Table 2

Change in the Intensity of Outgoing Radiation ΔI_∞ Near the Wavelength of 4.6 μm Upon the Appearance of a Polluting Layer of Carbon Monoxide.

Atmosphere	Carbon Monoxide Concentration *ppm*	ΔI_∞, %
Standard	1	0,05
$T_s = 288$ K	10	0,26
$\bar{T}_a = 287$ K	100	0,80
Standard	1	1,85
$T_s = 298$ K	10	6,56
$\bar{T}_a = 287$ K	100	16,63
Standard	1	−2,65
$T_s = 278$ K	10	−9,20
$\bar{T}_a = 287$ K	100	−22,96
Tropical	1	0,02
$T_s = 305$ K	10	0,06
$\bar{T}_a = 304$ K	100	0,32
Arctic Winter	1	−1,74
$T_s = 247$ K	10	−6,49
$\bar{T}_a = 251$ K	100	−16,98

values of the temperature of the earth's surface T_s (in order to allow for the influence of the daily temperature variation) and for the average temperature of the pollutant layer $\overline{T}_a$.

Naturally, the "sensitivity" of the outgoing radiation to the concentration of the polluting component depends decisively on the temperature contrast $T_s-\overline{T}_a$. At low temperature contrasts, the values of ΔI_∞ do not exceed the range of measurement errors (the existing instrumental capabilities permit one to achieve a measurement accuracy of not more than 0.5-1% [5]). However, on the whole, the example of the calculation pertaining to one of the principal polluting components gives encouraging results.

The authors of reference [8] also studied the influence of the nature of the vertical profile of the pollutant concentration (for a constant total content of the pollutant) on the magnitude of outgoing radiation. Detailed calculations of this kind were made for ammonia (wavelength, 10.8 μm). These calculations revealed an essential dependence of the outgoing radiation on the type of vertical distribution of the polluting component.

Figure 2 shows the calculations made by the authors cited in [8] for the spectral distribution of the values of $\Delta I_\infty(\lambda)$ as a function of the wavelength for eight components of pollution separately, and also the total effect of all these components (it is of course understood that the total effect is not additive) for standard atmosphere conditions. The spectral resolution capacity was 0.1 μm. The values of maximum gas concentrations n_{max} indicated on the figure correspond to approximately one-tenth of the concentration typical of the level of the earth's surface in the case of moderate and heavy pollution. It is evident that the overall curve shows most distinctly the peaks corresponding to carbon monoxide and sulfur dioxide.

The data of Fig. 2 clearly revealed the existence of a complex problem of overlapping of the emission bands of the individual gases. The situation obviously becomes even more complicated if one takes into account the influence of a series of bands that have not been considered, particularly those belonging to water vapor and carbon dioxide. It follows that the first requirement for a successful solution to the problem of determination of the content of a polluting component from measurements of outgoing radiation consists in separating a spectral interval where the absorption spectra of this and other components do not overlap. Obviously, such a requirement can best be met by selecting sufficiently narrow spectral intervals.

Since the outgoing radiation is chiefly determined by the vertical distributions of the temperature and radiating component (in the absence of band overlap), it follows that the first step in the solution to the problem of determining the vertical profile of the concentration of the polluting component should be the determination of the change of temperature with height. Since at the present time the objective of thermal sounding of the atmosphere

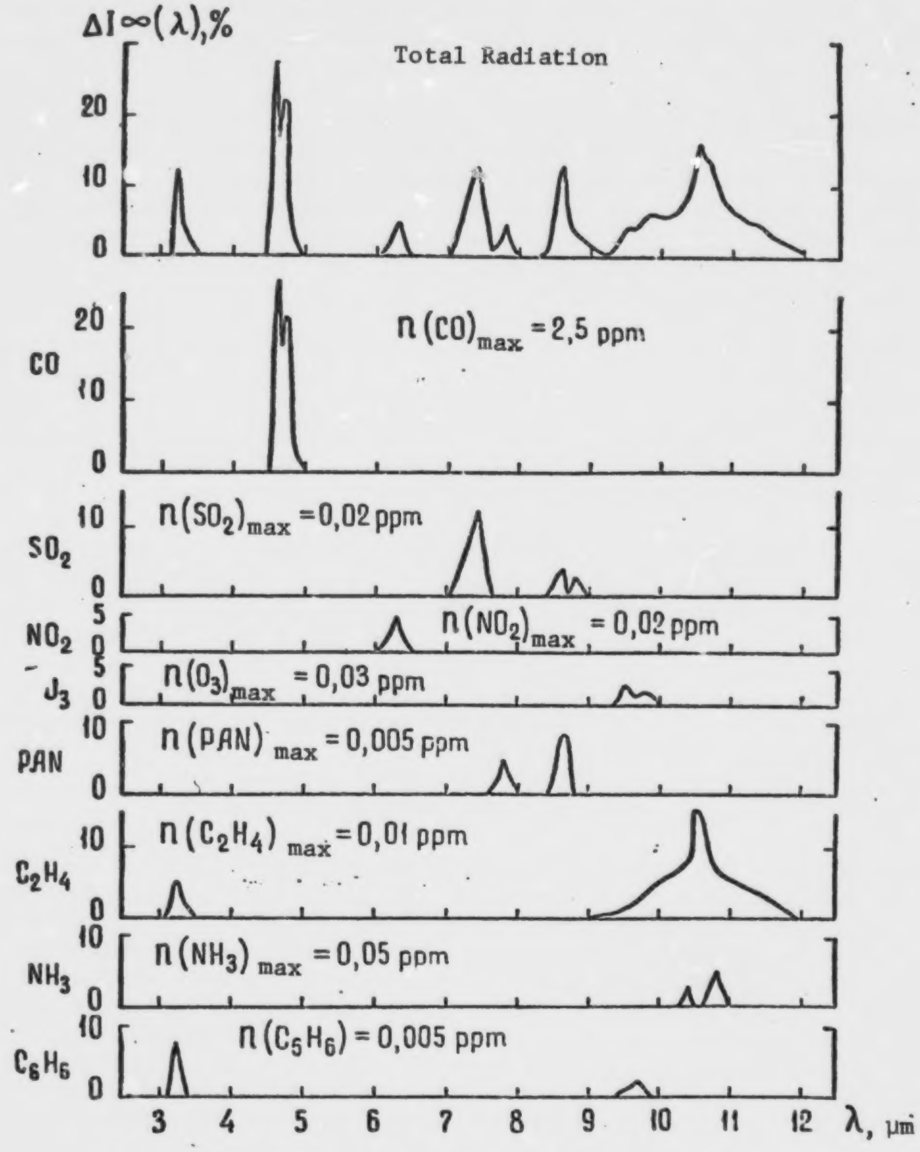

Fig. 2. Change of the outgoing radiation $\Delta I_\infty(\lambda)$ for different polluting components as a function of wavelength (PAN - peroxyacetyl nitrate).

from satellites may be considered practically accomplished (cf. [3]), this does not present any particular difficulties. Moreover, the mathematical methods worked out for solving the problem of thermal sounding can also be applied to the interpretation of data on measurements of outgoing radiation for the purpose of determining the content of the polluting components.

In this connection, a great importance is assumed by the considerable dependence of the solution on the correctness of the nucleus of the integral equation of the problem, i.e., on how reliable is the determination of the derivative of the transmission function, a dependence observed in solving reverse problems of satellite meteorology. The existing data on the transmission functions of the above polluting components of the atmosphere cannot be regarded as more than tentative. There is no question, therefore, that the insufficient spectroscopic study of these components constitutes a serious obstacle to the development of satellite methods of determining their content in the atmosphere. Although work has now begun on a comprehensive approach to the solution of reverse problems, in which the measurement data on the outgoing radiation are used for an independent determination of the derivatives of the transmission function, this work cannot as yet be considered close to practical applications.

Research conducted thus far of the problem of determination of the vertical humidity profile has shown that one of the serious obstacles is due in this case to "bad" weighting functions, which determine the vertical distribution of the relative contribution of the individual layers of the atmosphere to the outgoing radiation (cf. [3]). Apparently, this difficulty should also characterize the solution of the problem of content of polluting components.

Finally, let us note that all the results of calculations discussed above pertain to clear sky conditions. This signifies that the use of measurement data pertaining to actual conditions will give rise to the same problems concerning the consideration of the influence of the cloud cover as in the familiar case of thermal sounding of the atmosphere. The situation is even considerably more complex, since of greatest interest is the determination of the concentration of polluting components near the earth's surface.

As in the case of the problem of thermal sounding, one can attempt to solve the problem of influence of the cloud cover by using the microwave region of the spectrum. However, the considerable overlap of numerous lines of individual components of the atmosphere makes the use of the microwave region very difficult.

In conclusion, it may be stated that the use of data on spectral measurements of outgoing heat radiation in the infrared region of the spectrum is more promising from the standpoint of development of the satellite method of determining the polluting components of the atmosphere. The existing data show that despite many difficulties, suitable efforts aimed at the development of a method of this type should yield fruitful results.

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POLLUTION OF THE GROUND LAYER OF THE ATMOSPHERE DURING TEMPERATURE INVERSIONS

(Zagryazneniya Prizemnogo Sloya Atmosfery
Pri Temperaturnykh Inversiyakh)

A. I. Burnazyan, B. A. Bogdanov, L. F. Glebova, V. M. Kozlov,
V. V. Malakhova, G. I. Solomina, E. N. Teverovskiy, G. V. Chernega

A. I. Burnazyan, Editor

Izdatel'stvo "Meditsina"
Moskva, 1969

Introduction

Among the measures formulated by the Directives of the Twenty-Third Congress of the CPSU are recommendations concerning the need for improving the sanitary conditions of populated areas for a more vigorous struggle with the pollution of water and air reservoirs in towns, cities, and workers' settlements, and for nature conservation, particularly in suburban zones of industrial cities.

At the Fifteenth All-Union Congress of Hygienists and Public Health Physicians, held in Kiev in May 1967, it was noted that today there are still cases of pollution of water reservoirs, soil, and atmosphere by toxic substances discharged by industrial enterprises.

At this congress, the minister of public health of the USSR, B. V. Petrovskiy, emphasized the implementation of ameliorative measures aimed at preventing and eliminating the pollution of water reservoirs, soil, and atmospheric air, and the pollution of industrial centers with noxious discharges and household waste. These measures assume a particular importance at the present stage of rapid development of all branches of industry and introduction of chemical processes into the national economy.

We know that in one day, a man consumes about 1 kg of food, 2.5 l of water and 12 kg of air. Hence, air is the chief product being consumed, and it, therefore, should be the purest. Pure, uncontaminated air is extremely important in preserving and sustaining human health. Thus the problem of preventing air pollution assumes a great importance. The problem of sanitary protection of the atmosphere of towns, cities, and workers' settlements has become particularly acute.

The chief sources of air pollution are industrial enterprises, thermal electric power plants, industrial boiler houses, and also internal combustion engines.

As the industry develops and towns grow in size, the demand for various types of fuel rises sharply, causing an increase in air pollution from the discharge of products of combustion of solid and liquid fuel (gas, smoke, soot).

The air of developed industrial centers with a high industrial concentration is constantly being contaminated by discharges of various industrial wastes. The control of these discharges is being given considerable attention, but the increase in the discharges is approximately proportional to the industrial growth.

At the present time it is becoming increasingly clear that the pollution of atmospheric air may pose a threat not only to man's health, but also to his life. This pollution becomes particularly dangerous under certain specific meteorological conditions. Interest in these problems has increased since the well-known disaster in the Maas Valley in Belgium (1930).

The presence of such disasters and the recent sharp rise in the mortality rate because of air pollution under unfavorable meteorological conditions in London (1948, 1952, 1956, 1962), Donora (Pennsylvania, U.S.A., 1948), Posa Rica (Mexico, 1950), New York (1953, 1962, 1963), and other places demonstrate that air pollution in the towns, cities, and industrial centers of capitalist countries has reached such proportions that it has adversely affected the living conditions of the population.

The cause of these disasters was smog,* a toxic fog formed as a result of pollution of atmospheric air with noxious gases under unfavorable meteorological conditions.

A toxic fog may form when poisonous substances are present in air in relatively low concentrations during quiet windless weather and a temperature inversion, i.e., under meteorological conditions not conducive to dispersal and causing the accumulation of atmospheric pollutants in the ground layers of the atmosphere and a sharp increase in the concentrations of poisonous substances in the zone of human breathing.

In the present brochure, using an actual case of large-scale poisoning of the population with sulfur oxides as an example, the authors intend to direct the attention of the scientific medical community and representatives of those branches of industry which are responsible for atmospheric pollution to the necessity of intensifying the efforts toward achieving air purity in urban and industrial centers.

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* Editor's note: The term smog was formed from the words smoke and fog.

POLLUTION OF THE ATMOSPHERIC AIR OF INDUSTRIAL CENTERS WITH FLUE GASES

Despite the measures taken toward purifying noxious industrial emissions, the rapid development of industry has caused the air of industrial centers to contain different amounts of various chemicals in the form of gases, vapors, and aerosols. Particularly complex is the background of atmospheric pollution in areas where petrochemical and chemical enterprises are located, i.e., where the quantitative and qualitative composition of the emissions requires a thorough study. Among the industrial atmospheric pollutants in modern cities, the major ones continue to be sulfur oxides, whose absolute amounts are large as a result of their discharge with flue gases of thermal electric power plants and with the waste gases of industrial enterprises (petroleum refineries, petrochemical, sulfuric acid plants, etc.). This is due to the combustion of low-grade, high-ash types of solid fuel with a high sulfur content, and the combustion of high-sulfur mazuts. The combustion of solid fuel contaminates the air with ash, unburned fuel particles, and soot and sulfur oxides, chiefly sulfur dioxide. At the same time, the magnitude of pollution of air with flue gases depends on the quantity, quality, and mode of combustion of the fuel, the efficiency of the existing gas purification equipment, and the height of the smokestacks [1]. Solid fuel is burned by two basic methods, the pulverization and layer methods. Thermal electric power plants usually have pulverized-fuel furnaces, whereas heating boilers of low capacity are equipped with layer furnaces.

In the pulverization method of fuel combustion, the carry-over of fly ash with the flue gases accounts for approximately 80-90% of the ash content of the fuel, with 74.5-90% of the dust particles having a particle size of less than 10 μ. These fractions are the most offensive in the biological sense.

In addition, fly ash contains 4-24% of free silicon dioxide (SiO_2) [1, 2].

In the pulverization method of combustion, the sulfur contained in the solid fuel (pyrite and organic sulfur) burns up almost completely, forming chiefly sulfurous anhydride.

In the layer combustion of fuel, depending on the design of the furnace, the discharge of fly ash with the flue gases amounts to 20-30% of its content in the fuel. In contrast to the pulverization method of combustion, in the layer method part of the sulfur contained in the fuel remains unburned, and settles out in the slag in the form of cinder. It is commonly assumed that about 75% of the sulfur burns up in this case, so that the amount of sulfur dioxide reaching the atmosphere in the layer method of combustion will be 25% less for each ton of burned fuel than in the case of the pulverization method.

Of all the types of solid fuel, the largest amount of sulfur and ash is present in Moscow coals (sulfur content 2.5-6.0%, ash 35-50%), Kizel coal (ash content 30.0%, sulfur 7.0%), Lisichansk coal (ash content around 20%, sulfur 4%). Among shales, the Volga ones are high in sulfur (4.0-4.5%), and their ash content is 30.0-65.0%.

Highly unfavorable from a sanitary standpoint is the combustion of coal preparation waste, mainly of the industrial product, in which the sulfur content may reach 11%, and that of ash, 40-50%.

Thus, depending on the amount and quality of the solid fuel burned, thermal electric power plants and boiler houses can discharge considerable amounts of sulfur dioxide and fly ash into the atmosphere (Table 1) [3].

As is evident from the data of Table 1, the absolute discharges of ash and sulfur dioxide with the flue gases of electric power plants may amount to many tens and hundreds of tons per day.

In connection with the development of the petroleum refining industry, the combustion of mazut at thermal electric power plants and in industrial boiler houses is becoming increasingly important in the USSR as well as abroad.

Table 1.

Discharge of Sulfur Dioxide with Flue Gases of Electric Power Plants Operating on Solid Fuel.

Arbitrary Designation of Thermal Electric Power Plant	Consumption of Fuel (t/hr)	Content (в %)		Discharge of Sulfur Dioxide	Discharge of Ash Taking the Ash Trapping into Account (in t/day)
		Sulfur	Ash	(In t/day).	
	580	0,85	45	240	1 296
	500	2,5	25	600	672
	460	2,6	24	568,8	196,8
	280	2,74	28,7	374,4	160,8
	260	0,44	15	55,1	80,6
	180	2,83	25	240	127,2
	252	2,4	23	290,4	504

Mazuts, used as fuel for boiler houses, are primarily sulfur and high-sulfur mazuts containing 3-4.5% sulfur or more. Particularly unsuitable from a sanitary point of view are high-sulfur mazuts obtained from the refining of high-sulfur crudes.

Sulfur in mazuts is present mainly in the form of organic compounds, free hydrogen sulfide, and elemental sulfur. During the combustion of mazut in the furnaces of boilers and electric power plants, almost all of the sulfur is discharged into the atmosphere in the form of sulfur dioxide with the flue gases. The magnitude of absolute discharges of sulfur dioxide into the atmosphere as a function of the sulfur content in the mazut being burned can be evaluated from the calculated data of Table 2.

Table 2.

Absolute Discharge of Sulfur Dioxide with the Flue Gases of Electric Power Plants Burning Mazut (in t/days).

Power of Plant (in Thousands of kW)	Sulfur Content of Mazut (in %)					
	1	1.5	2	3	3.5	4.5
	Absolute Discharge (in t/days).					
600	—	78	104	156	182	226
900	—	117	156	234	273	351
1 200	104	156	208	312	362	466
2 400	208	312	416	624	728	936
4 800	416	624	832	1 248	1 456	1 872

As a result of the development of thermal power engineering and construction of high-output thermal electric power plants, i. e., 2400-4800 MKW and above, the absolute discharges of sulfur dioxide during the combustion of mazut as well as coal are very considerable.

On the basis of the above it may be concluded that sulfur compounds and ash are of great sanitary importance as factors in air pollution.

An important part is also played by the discharges of gases from numerous furnaces, boiler houses and transport vehicles burning mazut and low-grade fuels. Of interest in this regard are examples of absolute discharges of sulfur dioxide during the combustion of solid fuel in the combustion chambers of boiler houses, house furnaces, and electric power plants in certain foreign cities.

In England, 190 million tons of coal was burned in 1948, so that the discharges of sulfur dioxide amounted to 4.7 million tons [46]. In New York, as a result of the combustion of 30 million tons of coal, around 1.5 million tons of sulfur dioxide is discharged into the atmosphere every year. In France, the thermal electric power plants of "Electricité de France" (EDF) discharged into the atmosphere 114,000 tons of sulfur dioxide and 82,400,000 tons of ash in 1960. According to the data of the Paris Hygiene Laboratory, around 178,000 tons of sulfur dioxide is discharged into the atmosphere of the city every year, 52% being due to the flue gases of house furnaces. This led the French Minister of public health, B. Sheno [Chennault], to state at the opening of the First National Congress on the

Control of Atmospheric Pollution, in November 1960, that air pollution, whose victims are the inhabitants of large cities and industrial centers, is currently becoming a major calamity and steps must be taken to combat the growing pollution [4].

At the present time, a considerable body of data has been provided by sanitary-hygienic studies of pollution of urban air with sulfur dioxide.

In the neighborhood of a high-capacity electric power plant discharging 280-360 tons of sulfur dioxide per day, the maximum concentrations of this gas on the leeward side were 0.3-4.9 mg/m^3 at a distance of 200-500 m; 0.7-5.5 mg/m^3 at a distance of 500-1000 m; 0.22-2.8 mg/m^3 at a distance of 1000-2000 m [5].

In the vicinity of an isolated boiler house which discharged about 7 tons of sulfur dioxide per day, the maximum sulfur dioxide concentrations were 1.4-11.97 mg/m^3 at a distance of 200 m, 0.16-1.0 mg/m^3 at a distance of 300 m, 0.10-0.6 mg/m^3 at a distance of 600 m, and 0.14-0.2 mg/m^3 at a distance of 1000 m from the source of the discharge [5].

The importance of absolute discharges of sulfur dioxide in the pollution of atmospheric air is shown in Table 3 [3].

Table 3.

Maximum Sulfur Dioxide Concentrations in Atmospheric Air Around Electric Power Plants.

Arbitrary Designation of Thermal Electric Power Plant	Absolute Discharge (in t/hr)	Height of Smoke-stacks (in m)	Maximum Concentrations of Sulfur Dioxide (in mg/m^3) in Atmospheric Air at a Distance of (in km).					
			0.5	1.0	2.0	3.0	4.0	5.0
A	10	120	0,24	0,23	0.3	0,28	—	0,17
B	25	45	19,1	13.3	3,8	—	—	—
C	23,7	120	1,3	1,9	1,3	1,5	0,9	0,9
D	15,6	120	0,6	1,1	1,1	1,1	0,3	0,3
E	2,3	105	0,3	0,4	0,3	0,2	—	—
F	10	150	0,48	0,6	0,7	0,72	—	0,6
G	12,1	120	0,73	0,51	1,06	0,30	—	—

As is evident from Table 3, in the study of the degree of atmospheric pollution around thermal electric power plants, high concentrations of sulfurous anhydride were observed in the air at a distance of up to 3 km for an absolute discharge of 15.6 t/hr and above through high stacks (120 m). An extremely high air pollution was observed around an electric power plant discharing 25 t/hr of sulfurous anhydride through low stacks (45 m).

Table 4 shows the magnitude of maximum concentrations of fly ash in the atmospheric air around the electric power plants.

Sanitary studies [5, 6, 7, 8] established that the meteorological conditions have a major influence on the degree of atmospheric pollution with sulfur dioxide. Factors causing an increase in sulfur dioxide concentrations in the air of cities are a low barometric pressure, low wind velocities, a low temperature, a high relative humidity, and fog.

In addition to sulfurous anhydride, the flue gases of electric power plants and boiler houses always contain sulfuric anhydride, which amounts to 1-3% of the total concentration of sulfur oxides in these gases [5].

Table 5 presents data on the content of sulfurous and sulfuric anhydrides in the waste gases of enterprises and in the atmospheric air of certain cities [9].

Table 4

Maximum Concentrations of Fly Ash (in $\mathrm{mg/m^3}$) in the Atmospheric Air Around Electric Power Plants

Designation of Thermal Electric Power Plant	Absolute Discharge (in t/hr)	Height of Smokestack (in m)	Maximum Concentrations of Dust (in $\mathrm{mg/m^3}$) at a Distance of (in km)						
			0.5	1.0	1.5	2.0	3.0	4.0	5.0
A	54	120	6.6	4.5	—	8.4	6.1	—	4.4
B	28	45	51.0	24.9	—	9.9	2.6	—	—
C	8.2	120	1.1	2.7	2.2	1.8	0.9	0.5	0.3
D	6.7	120	1.0	2.1	3.9	3.0	1.4	0.5	—
E	3.4	105	1.1	0.9	0.4	0.8	—	—	—
F	5.3	150	0.28	0.4	—	1.1	1.5	—	0.17

Since sulfuric anhydride amounts to about 1-3% of the total concentration of sulfur oxides in the flue gases of boiler houses and electric power plants, one can calculate the approximate discharge of sulfuric anhydride into the atmosphere as a result of combustion of different types of fuel.

The approximate discharge of sulfuric anhydride with flue gases during the combustion of different types of solid fuel can be seen from Table 6 [5].

It may be expected that the combustion of 500 t/hr of Moscow and Kizel coal will result in the discharge into the atmosphere of about 12.4 and 24.48 t/day of sulfuric anhydride respectively, which approaches the absolute discharges of sulfuric acid plants. In a large city with a population of several million people, consuming 60,000 tons of coal per day, the discharge of sulfur dioxide may amount to 50-180 tons, which adds even more urgency to the problem of pollution of the air reservoir of industrial cities with sulfur oxides.

Table 5

Content of Sulfurous and Sulfuric Anhydrides (SO_2 and SO_3) in Atmospheric Air and in Waste Gases (the Smoke was Analyzed in the Smokestack).

Item Studied		SO_2 Concentration (Vol. %)	SO_3 Concentration (g/m^3)
Air of large city	Berlin	0,000053	0,0019
	London	0,00039—0,014	—
	Glasgow	0,00042—0,015	—
	Cleveland	0,002	0,075
Small English town		0,000013	0,00047
Smoke from locomotive.		0,03	0,12
Factory smoke (average)		0,112	4,0
Wood smoke		0	0
Coal smoke (near combustion chamber)		0,046—0,08	1,7—3,0
Smoke of steam boiler.		0,063	2,25
Smoke of house furnace		0,037—0,04	1,33—1,43
Industrial Plants			
Smoke from smelting of copper ore .		1,7	60,75
Smoke of roasting furnaces		8,5	278,7
Smoke of cellulose plants.		0,025	0,9
Smoke of ultramarine plants . . .		0,5—3,5	17,9—125,0
Smoke of sulfuric acid plants. . .		0,13—0,45	4,6—16,1

Experimental studies [10] established that sulfuric anhydride is practically not observed in clear weather. In cloudy weather, the sulfuric acid aerosol concentration in average daily samples was 6.8%, during variable cloudiness 5.1%, and in clear weather, only about 3.2%. In foggy weather, the content of sulfuric anhydride as the product of oxidation of sulfur dioxide may amount to about 15.7% of the concentration of sulfur dioxide. It was noted that the percentage of sulfur dioxide which changed into sulfuric acid aerosol was greater the longer and heavier the fog. Thus, in one of the single samples, the concentration of sulfuric acid aerosol was 32% of the concentration of sulfur dioxide.

Table 6

Discharge of Sulfuric Anhydride with Furnace Gases for Different Types of Fuel

Name of Coal	Concentration (in mg/m^3) of furnace gases	Discharge (in g/ton) of Burned Fuel
Kuznetsk	14,6	160
Donetsk	63,2	720
Moscow	208,0	1 040
Kizel . . .	232,0	2 040
Shales	454,0	1 360

A gradual conversion of sulfur dioxide into sulfuric acid aerosol in the atmosphere is promoted by the humidity of the air and the presence in the latter of condensation nuclei, i.e., ash and highly dispersed aerosols of metal sublimates, which are catalysts always present in the air of industrial centers.

Thus, the pollution of the atmospheric air of certain industrial centers during the combustion of mineral fuel may reach considerable proportions and constitute a threat to the health of the population.

Brief Description of the Chemical Properties and Toxicity of Substances Discharged During the Combustion of Fuel into the Atmosphere

The main chemical substances discharged into the atmosphere with the flue gases during the combustion of fuel are sulfur oxides (sulfurous and sulfuric anhydrides), fly ash, and carbon monoxide. The flue gases of boiler houses may also contain other chemical compounds forming during the combustion of solid and liquid fuels, in particular, nitrogen oxides, boron oxides, etc.

The part played by these compounds in the pollution of the atmosphere during the combustion of fuel has not been completely determined.

Sulfurous anhydride (SO_2, molecular weight 64.06) is a colorless gas with a pungent odor that decreases at low temperatures. When dissolved in water, it forms sulfurous acid. It has reducing properties.

The clinical picture of acute poisoning of experimental animals exposed to low concentrations of SO_2 consists in the irritation of the mucosa of the respiratory tract and eyes.

At higher concentrations, the symptoms observed are cyanosis of the visible mucous membranes, marked dyspnea, and sometimes convulsions and death. Autopsy of the dead animals shows mucous-purulent or fibrinous coatings in the respiratory tract, hyperemia and edema of the lungs, and hemorrhages in the latter.

When animals are exposed to a mixture of sulfurous anhydride and carbon monoxide or to particles of a thick, highly dispersed fog, the toxicity of sulfur dioxide increases sharply.

Until recently, it was commonly believed that on reaching the mucosa of the upper respiratory tract, sulfur dioxide forms sulfurous acid (H_2SO_3), which oxidizes to sulfuric acid (H_2SO_4), and the latter causes serious injury to the upper respiratory tract. This does not assume the penetration of sulfur dioxide directly into the blood, and thus its general resorptive effect has been denied.

However, an extensive experimental material accumulated in the last few years has shaken these assumptions. It was established that the blood takes up sulfur dioxide very quickly and readily [11-16]. Sulfur dioxide was shown to be present in the blood as early as 20 minutes after being inhaled and some time after breathing has ceased. In the organism, this gas is not uniformly distributed. Its largest amounts are observed in the lungs, bone marrow and liver [17]. When sulfur dioxide is inhaled every day, after 3-4 days the products of its transformation accumulate in the body.

Thus, during inhalation of sulfur dioxide labeled with a sulfur isotope (S^{35}), the gas was found in all the viscera, particularly in the lungs, but also in the urine and stool three weeks after poisoning [15].

Various points of view exist on the mechanism of the general toxic action of SO_2. Some researchers [12, 15] regard nervous mechanisms to be the leading ones in the development of intoxication, on the basis of the fact that even slight concentrations of this gas cause a number of disturbances in the nervous reflex activity of experimental animals. Other authors [18] attribute a special importance to the sharp depression of immunobiological protective mechanisms.

In the view of still others [14], the leading role in the pathogenesis of poisoning is that of disturbance of enzymatic oxidation processes, breakdown of thiamine, and oxygen starvation of tissues.

The toxic concentrations of sulfur dioxide are different for different experimental animals. Thus, in white mice, death occurred after the inhalation of this gas for 10 minutes in a concentration of 3.5 mg/l, and in white rats, in a concentration of 2.6 mg/l. In guinea pigs, the inhalation of sulfur dioxide in a concentration of 2-2.6 mg/l for 30 min to 1 hour did not result in death.

For man, the threshold of perception of the sulfur dioxide odor is 0.006-0.003 mg/l. During exposure, irritation of the eyes is caused immediately by a concentration of 0.05 mg/l, irritation in the throat by concentrations of 0.02-0.03 mg/l, and cough by a concentration of 0.05 mg/l A concentration of 0.12 mg/l can be tolerated for 3 min, and 0.3 mg/l, for only 1 minute.

Recent studies have established slightly lower values of the perception threshold of sulfur dioxide odor for man [18]. According to these data, a definite odor of sulfur dioxide is perceived by all people in concentrations of 0.005-0.007 mg/l. Most persons, however, perceive the odor of this gas in concentrations of 0.0026-0.003 mg/l, and the most sensitive ones, even in a concentration as low as 0.0016 mg/l. At low temperatures, a decrease of the olfactory sensitivity is observed.

The maximum permissible concentration of sulfur dioxide for the air of industrial buildings is 10 mg/m^3; for atmospheric air, the highest single concentration is 0.5 mg/m^3, and the mean daily concentration, 0.05 mg/m^3.

Sulfuric acid fog (H_2SO_4, molecular weight 98.08) consists of extremely fine particles (a few microns in size) of sulfuric acid in the atmosphere. As a rule, sulfuric acid aerosol is present in air simultaneously with sulfurous anhydride, which, depending on the humidity of the air, partially forms sulfuric acid aerosol [5, 10].

The degree of injury to the lungs depends not so much on the aerosol concentration as on the duration of its action and also on the particle size of the aerosol: the latter determines the level of greatest injury (bronchi, bronchioles, alveoli). For example, guinea pigs inhaling H_2SO_4 aerosol with a particle size of 2.5 μ in high concentrations developed a bronchial spasm and breathing disturbances. Particles 7 μ in size caused only slight changes in breathing, even when the aerosol was inhaled in a concentration of 0.03 mg/l for 1 hour [18].

Sulfuric acid aerosol, like sulfurous anhydride, has also a general toxic effect on the organism [19]. The studies were carried out on rats subjected to the inhalational action of sulfuric acid aerosol labeled with a sulfur isotope (S^{35}). It was noted that in a single inhalational exposure, the sulfuric acid aerosol rapidly enters the blood. The conversion products of sulfuric acid are carried into all the organs and tissues, remaining there for a long time (up to 10 days). Their distribution in the organs and tissues is not uniform. In the first few hours after the exposure, the conversion products of sulfuric acid become localized mainly in the lungs, blood, liver, and large intestine, and are excreted from the organism through the kidneys and intestine.

The experiment also showed that the combined action of sulfuric acid aerosol and sulfur dioxide on the animals increases the toxic effect of the dioxide, i.e., a marked synergism is observed [20, 21]. The experiment demonstrated that the combined action of sulfuric acid aerosol and sulfur dioxide sharply aggravates an already existing pulmonary insufficiency (experimental silicosis in the animals) and may cause a fatal result at relatively low concentrations, i.e., three times lower than the IC_{50} for healthy animals.

These studies confirmed the cases of large scale poisoning with toxic fogs described in the literature, when persons with a chronic insufficiency of the cardiovascular and respiratory systems were the ones that suffered the most.

Fatal concentrations of sulfuric acid aerosol for white mice are 0.94 mg/l in a 4-hour exposure and 0.27 mg/l in a 24-hour exposure. White rats die after 7 hours at a concentration of 0.7 mg/l. For guinea pigs, the fatal concentration for an 8-hour exposure ranges from 0.05 to 0.18 mg/l, depending on the age of the animals [20].

For man, the threshold of odor perception and irritant effect of sulfuric acid aerosol is in the range 0.0006-0.00085 mg/l [22]. Reflex changes of breathing in healthy people were noted at concentrations of 0.00035-0.005 mg/l [20]. The threshold of the reflex effect on the inhalation of sulfuric acid aerosol was established at the level 0.0004 mg/l [22].

The maximum permissible concentration of sulfuric acid aerosol for atmospheric air is 0.3 mg/m^3 for the highest single concentration and 0.1 mg/m^3 for the average daily concentration.

Fly ash consists of a dust found in the atmosphere around electric power plants; 55 to 77% of this dust is made up of extremely fine solid particles, up to 5 μ in size. Chemical analysis of the dust established the presence of silicon dioxide both in the bound form and in the free state as alpha-quartz [2].

The content of free silicon dioxide in the fly ash around heat and electric power plants burning solid fuel of the type of Moscow coal may reach 20-30%, which is hazardous for the health of children residing in those areas for a long time [2, 26].

It is known that the dust particles of flue gases do not in themselves pose the danger of acute poisoning in man, but, as already indicated, the combined influence of sulfurous anhydride dust and sulfuric acid aerosol enhances the toxic effect of sulfur compounds. Moreover, the direct noxious effect of fly ash on the health of the population may be manifested in street traumata of the eyes caused by ash particles. In large industrial cities, these traumata constitute 30-60% of all the urgent cases of treatment of eye disturbances [24, 25].

Carbon monoxide (CO, molecular weight 28.01) is a colorless gas. It is present in the flue gases of boiler houses and electric power plants; calculations show that the combustion of 1 ton of fuel forms up to 20 kg of carbon monoxide [5].

Despite the relatively large quantities of emitted carbon monoxide, boiler houses and electric power plants do not play a major role in the total pollution of atmospheric air with carbon monoxide.

Emissions of carbon monoxide from blast-furnace and coking plants, automobile engines, etc., are vastly more important in the pollution of atmospheric air with carbon monoxide.

No cases of large-scale poisoning with carbon monoxide in the open air have been described in the literature.

The maximum permissible concentration of carbon monoxide in the air of industrial buildings is 30 mg/m^3, the average daily concentration in atmospheric air is 1 mg/m^3, and the highest single concentration is 6 mg/m^3.

Nitrogen oxides (NO, NO_2, N_2O_3, N_2O_4). A mixture of different nitrogen oxides is discharged into the atmosphere during the operation of internal combustion engines, during the combustion of various nitrogen-containing organic compounds (celluloid, motion picture film, etc.), and with emissions of vapors of nitric acid in the industrial production of the latter. Nitrogen oxides may also be present in the flue gases of boiler furnaces. No cases of poisoning of the population or individuals by nitrogen oxides contained in the flue gases of boiler houses are known in the literature.

Clinical Picture of Acute Cases of Poisoning with Sulfur Compounds in Man

As follows from the preceding section, sulfurous anhydride plays the principal role in the possible toxic action of fuel combustion products. The noxious effect of sulfur dioxide (SO_2) on the organism was known as long ago as the Middle Ages, when this gas was used during the siege of cities. Much later, reports appeared in the literature on the great frequency of eye inflammations, hoarseness and complaints of cough among workers employed in the processing of sulfur and bleaching of fabrics [27].

In the domestic literature, the largest number of descriptions of cases involving acute poisoning pertain to the 1920's-30's. All the investigators who have described cases of large-scale poisoning as well as individual cases of acute intoxications with sulfur dioxide note that even very low concentrations of sulfur dioxide have an irritant effect on the mucous membranes of the upper respiratory tract [10, 28, 29, 30, 31].

Higher concentrations of sulfur dioxide cause lacrimation, acute conjunctivitis, inflammation of the upper respiratory tract and bronchi, and impairment of speech and swallowing, this being accompanied by an accelerated pulse and a decrease in breathing capacity [32].

The action of high concentrations causes dyspnea, cyanosis and an impairment of consciousness [10]; a rapid development of bronchitis, bronchopneumonia, and pulmonary edema is possible [33, 34]; the appearance of bronchiectasis has been described.

Most authors hold the view that acute fatal cases of poisoning with sulfur dioxide occur relatively seldom, since the irritating odor of sulfur dioxide signals the danger of poisoning very early. The inhalation of air containing 1.5 mg of SO_2 per liter makes it impossible to breathe in fully because of the marked irritation of the respiratory tract and spasm of the glottis [35, 36].

Death may also occur as a result of an acute disturbance of the blood circulation in the lungs or as a result of shock [9]. Cases are also possible in which death takes place a few hours after poisoning as a result of pulmonary edema [10].

The domestic literature describes lethal results of poisoning with sulfurous anhydride [40, 41]. In a case [37] with a lethal result, autopsy on the 7th day showed the presence of heavy "croupous" pneumonia [38].

In large-scale poisoning with sulfur dioxide at a sulfite cellulose factory, two of the 18 victims died, and 8 people lost their working capacity because of the development of pulmonary emphysema and chronic bronchitis [38]. Autopsy of the dead showed marked inflammatory changes of the respiratory tract, pulmonary edema, and hyperemia of the spleen, liver, and kidneys.

Many reports have been published on the local effect of sulfurous anhydride on the skin and mucous membranes of the eyes. A case was observed in which, after a 2-minute exposure to an atmosphere containing 26 mg/l of SO_2, a worker showed an extreme irritation of the skin [9]. As a result of the action of sulfurous anhydride on the face and eyes, blisters appeared on the skin, edema on the eyelids, and purulent conjunctivitis and necrosis of the cornea [occured]. From the above descriptions by various authors it is evident that the clinical picture of acute poisoning with sulfur dioxide with a clearly defined irritant effect consists in a predominant injury of the respiratory organs and primarily of the upper respiratory tract.

Objective symptoms of acute sulfur dioxide poisoning of slight degree are characterized by an acute catarrhal laryngotracheitis and acute catarrhal conjunctivitis. In addition, one can objectively observe hyperemia and edema of the mucosa of the larynx, trachea, and vocal chords, and diffuse hyperemia of the conjunctiva and frequently edema. The symptoms of general intoxication associated with this degree of poisoning are slight and are observed in a small number of patients. As a rule, these changes can be readily treated and do not leave any complications.

A poisoning of moderate degree is marked by pronounced changes of the mucous membranes of the eyes and upper respiratory tract. Acute conjunctivitis is accompanied by blepharospasm and photophobia. In some patients, point opacities of the cornea may remain after the elimination of acute conjunctivitis.

Symptoms of laryngotracheitis frequently combine with acute bronchitis, which is associated with attacks of choking cough. In this degree of injury, the inflammatory process frequently extends to the small bronchi and bronchioles, as indicated by heavy dyspnea, orthopnea, acrocyanosis, subfebrile temperature, and the presence of moist crepitant rales in the lower areas of the lungs along with dry rales in the lungs. Diffuse toxic bronchitis is frequently accompanied by pulmonary emphysema and asthmatoid states.

Symptoms of general intoxication are found more frequently and are expressed more clearly in the form of neurocirculatory disturbances and changes in the functions of the liver and kidneys. The illness lasts 1 to 1 1/2 months, and the symptoms of general weakness, headache, and increased fatigability may linger on longer.

In the case of a high degree of poisoning with sulfur dioxide, the clinical picture is dominated by purulent tracheobronchitis accompanied by an acute diffuse emphysema of the lungs and bronchial asthma. The course of the illness is complicated by serious toxicoinfectious pneumonia, which in the majority of cases takes on a chronic course followed by development of pneumosclerosis and bronchiectasis. This degree of injury involves degenerative changes in the heart muscle and changes in the functions of the liver and kidneys.

Among the characteristic symptoms of acute intoxication with sulfur dioxide, one observes a high frequency (in the case of poisoning of moderate and high degree) of asthmoid states associated with eosinophilia in the blood and early acute distension of the alveoli (basal emphysema, and in serious cases diffuse pulmonary emphysema).

Among changes in the blood, the more frequent ones were eosinophilia (in 48.1% of the subjects), relative neutropenia (in 74%), monocytosis (in 58.1% of the subjects) and a staff cell shift (in 37% of the subjects).

Manifestations of the generally toxic effect of sulfur dioxide include degenerative changes in the heart muscle and vascular wall, functional disturbances of the liver in the form of bilirubinemia, urobilinuria, changes in the protein and carbohydrate functions, and nephropathy, manifested in albuminuria and michrohematuria. These symptoms are usually observed only in cases of acute poisoning of moderate and, especially, of high degree with this gas.

Considerable attention should be given to problems of differential diagnostics of acute cases of poisoning with sulfur dioxide versus poisoning by nitrogen oxides and carbon monoxide (Table 7).

It is evident from Table 7 that sulfur dioxide causes serious damage to the air-conducting tract, acute emphysema, and a protracted course of toxicoinfectious pneumonias. The action of nitrogen oxide causes a frequent development of pulmonary edema with a fairly indistinct injury of the upper respiratory tract. Toxic pneumonias caused by nitrogen oxides have a more favorable course than [those caused by] poisoning with sulfur dioxide. The action of carbon monoxide is characterized by a predominant injury to the central nervous and cardiovascular systems in the absence of changes in the upper respiratory tract.

The problem of the influence of sulfur dioxide on the human organism is indissolubly tied to the influence of sulfuric acid aerosol on the health of

Table 7

Frequency of Symptoms in Gas Poisoning
(According to N. P. Sterekhova)

	Symptoms and Nosological Forms	Frequency of Symptoms Associated with the Prevalence of the Following Gas in the Composition of Explosive Gases		
		Sulfur Dioxide	Nitrogen Oxides	Carbon Monoxide
Respiratory System	Cough	In all cases Often	Often	Very seldom
	Dyspnea	Very often	None	None
	Pain in chest	Connected with breathing, constantly	Slight intensity often	"
	Laryngotracheitis	In all cases	Very seldom	"
	Bronchitis	Same	Frequently	"
	Acute lung emphysema	Often	None	"
	Pneumonia	"	Less often	"
	Asthmatoid state	"	None	"
	Pulmonary edema	Very seldom	Often	"
Cardiovascular System	Heart palpitation	Often	Frequently	Very often
	Pains in the region of heart	Occasionally	None	Often
	Hypotonia	Often	Often	Very often
	Degenerative changes in heart muscle	"	Seldom	Often
	Ischemic foci in the myocardium	Isolated cases	None	Frequently
Nervous System	General weakness	Relatively often	Often	In all cases
	Impairment of consciousness	Very seldom	Very seldom	Very often
	Amnesic disturbances	None	None	Often
	Neurocirculatory dystonia	Frequently	Frequently	Very often
	Organic damage to the central nervous system	None	None	Often
	Psychic disturbances	"	"	Frequently
Others	Nephropathy	Frequently	None	None
	Hepatopathy	Very often	Often	Often
	Conjunctivitis	Same	None	None
	Eosinophilia	Often	Very seldom	"
Others	Carboxyhemoglobinemia	None	None	In all cases
	Increase of blood viscosity	In serious cases	Very often	None

workers, since the irritating effect of sulfur dioxide on the upper respiratory tract is due to its conversion into sulfurous and then sulfuric acid.

All the descriptions of acute cases of poisoning with sulfuric acid [42, 43, 44] pertain to the combined action of sulfuric acid and sulfurous anhydride. When inhaled by man, sulfuric acid aerosol causes irritation of the upper respiratory tract, particularly of the nasal mucosa: mucus, sneezing, cough, difficult breathing, burning of the eyes, and reddening of the conjunctiva take place. At higher concentrations, bloody sputum, vomiting (sometimes with blood) and later, grave inflammatory affections of the bronchi and lungs may appear [42, 43]. The x-ray picture of a fine-focus pneumonic process, which gradually developed in a man (in the course of 3 weeks) after he inhaled sulfuric acid vapors as a result of a storage tank leak, has been described [43].

A case of chronic affection of the lungs following an acute poisoning with sulfuric acid fog has been described. A man 40 years of age was exposed to sulfuric acid aerosol for 8 minutes at a plant, and this resulted in the development of pulmonary edema followed by inflammation of the lungs [42].

After 13 months, the patient died of aggravated pulmonary emphysema.

From the above studies it is evident that experiments and clinical practice have now accumulated sufficient facts indicating that sulfur dioxide and sulfuric aerosol, which have a marked local irritant effect on the mucous membranes of the eyes and upper respiratory tract, can enter the bloodstream [45] and cause changes in the parenchymatous organs, this being particularly pronounced in acute intoxications of moderate and of high degrees.

Cases of Large-Scale Poisoning of the Population as a Result of Air Pollution

Air pollution in major industrial cities is a problem attracting increasing attention in the scientific community. Studies published recently and dealing with this problem emphasize the serious harm done to public health and to the surrounding nature by emissions from industrial plants.

The world medical community has been made particularly aware of this problem in connection with the publication in the press of cases of disastrous atmospheric pollution and acute poisoning of the population in some foreign countries, involving unfavorable meteorological conditions. These cases are described in detail in the book of K. Barker, F. Kembi et al., "Pollution of Atmospheric Air", published by the World Health Organization [46], and in the book of L. Battan, "Polluted Sky" [50].

A case of large-scale poisoning of the population was observed in the valley of the Maas River (Belgium), when from December 1 to 5, 1930, as a result of anticyclones, all of Belgium was blanketed by a fog that was particularly thick in the river valleys, and in the Maas river valley, in addition to the fog, a temperature inversion took place.

The temperature inversion and fog caused a considerable accumulation of atmospheric pollutants up to toxic concentrations, produced by the emissions of industrial enterprises located in the valley, including ferrous metallurgical plants, coke-oven batteries and blast furnaces, steel foundries and zinc-smelting plants, electric power plants, a sulfuric acid producing plant, and an artificial fertilizer plant. On the third day, large-scale affections of the respiratory tract appeared in the inhabitants of this region. According to inaccurate data, the number of those affected was several thousand, and the number of persons who died during that period was about 10 times as high as the average mortality rate for this region. Among the dead were predominantly elderly persons with chronic heart and lung diseases.

The illness appeared in all the inhabitants, regardless of age, and was manifested by the following symptoms: lacrimation, irritation of the throat, hoarseness, cough, faster breathing, a sensation of tightness in the chest, nausea, and sometimes vomiting. A dry cough and faster breathing predominated in this case. After the fog dissipated, no new cases of illness were observed.

Studies aimed at elucidating the specific cause of large-scale illness of the population, begun immediately after the fog disappeared, showed that aside from the weather change, nothing unusual had occurred in the conditions characteristic of this area, i.e., not a single industrial enterprise had changed the type or intensity of its production.

A thorough study of the composition of the industrial emissions into the atmosphere enabled the commission to conclude that the cause of the large-scale illness was the simultaneous presence in the air of sulfurous anhydride and sulfuric acid aerosol. Calculation showed the sulfur dioxide content during that period reached 100 mg/m^3 [47]. It was also postulated that the nitrogen oxides contained in the air and the presence of highly dispersed solid particles of metal oxides acting as catalysts could have promoted the conversion of sulfur dioxide into sulfuric anhydride. The weather conditions had been studied for a number of years previously, and as a result it was found that similar combinations of meteorological conditions had also been observed earlier in the Maas River valley, but for a shorter period of time. Thus, under similar weather conditions in 1911, it was noted that the disease rate among the population increased, but without fatal results.

Large-scale poisoning of the population due to atmospheric pollution was observed in the town of Donora (Pennsylvania, U.S.A.) at the end of October 1948, when prolonged stagnating conditions of atmospheric air lasting four days and because of a deep temperature inversion and anticyclonal weather accompanied by fog and calm led to an unusually heavy accumulation of atmospheric pollutants in the ground layer. During these four days, large-scale illnesses of the respiratory organs appeared among the inhabitants of the town. The number of people affected was around 6,000 (43% of the population); those most often affected were 40-55 years old.

The most frequent symptom was cough. There were painful sensations in the pharynx, tightness in the chest, headache, burning in the eyes, orthopnea, lacrimation, vomiting, nausea, and profuse nasal discharges (Table 8) [46].

The mildest symptoms were considered to be: irritation in the eyes, lacrimation, nasal discharges, painful swallowing, dry cough, nausea without vomiting, headache, general weakness and pains in the muscles.

Moderate symptoms included cough with sputum, sensation of heaviness or constriction in the chest, dyspnea, vomiting, and diarrhea. The only grave symptom was considered to be orthopnea (sensation of suffocation).

During that same brief period, 17 fatal cases were recorded as against two cases usually observed.

Table 8

Symptoms Caused by Pollution of Atmospheric Air According to Frequency of Occurrence (in Decreasing Order) Among All the Population Age Groups

Symptom	Percent
Cough	33,1
Dry	20,2
With Sputum	12,9
Painful sensations in pharynx	23,1
Constriction in chest	21,5
Headache	17,0
Dyspnea without orthopnea	8,4
Lacrimation	8,0
Vomiting	7,4
Nausea without vomiting	7,1
Nasal discharges	6,6
Fever	2,6
Orthopnea	2,3
Painful movements	1,9
Weakness	1,8
Cyanosis	1,0
Diarrhea	0,1

Autopsy of the people who died during this disaster showed symptoms of acute irritation of the lungs in the form of dilation of the capillaries, hemorrhages, edema, purulent bronchitis and purulent bronchiolitis.

In order to identify the causes, a special survey was made on the population, engineering and technical studies were carried out to determine the quantitative and qualitative composition of the chemicals in the atmosphere during the fog and during operation of the plants at full capacity, and the necessary studies were carried out during the operation of local factories and plants at full capacity under the conditions of a brief temperature inversion. The local weather conditions and all the archive materials on weather during the preceding periods were investigated. It was found that similar atmospheric conditions had been observed in the town of Donora in April 1945, when a sudden increase of mortality was recorded there. On the basis of repetitions of such weather conditions in 1948, it was postulated that a possible relationship existed in 1945 between the high mortality rate due to cardiovascular diseases and the environmental conditions.

On the basis of an analysis of the results of medical, engineering-technical and meteorological studies, it was shown that the cause of mass poisoning of the population was sulfur dioxide combined with products of its oxidation and nonspecific dust particles.

In London, large-scale poisonings of the population during a disastrous pollution of the atmosphere have been observed repeatedly. Five such disasters were described most completely: in 1948, from 26 November to 1 December; in 1952, from 5 to 8 December; in 1956 from 3 to 6 November; 1957, from 2 to 5 December; in 1962, from 3 to 7 December. In November 1948, the number of fatal cases in London exceeded the average level by 300 cases; the pollution of atmospheric air during the inversion in January 1956 was accompanied by an excess of 1000 cases above the average mortality level.

The most detailed study was made of a disaster that occurred in December 1952 [46, 50]. On these days, many areas of the British Isles, the valley of the Thames River and particularly London were blanketed by a fog caused by anticyclonic weather conditions and a temperature inversion. Various kinds of injury to the respiratory tract in large numbers of inhabitants appeared approximately 12 hours after the formation of a thick fog that led to the accumulation of pollutants in the air. An unusually large number of fatal cases involving about 4000 people were recorded. The illness usually began abruptly, mostly on the 3rd-4th day of foggy weather.

The illnesses were characterized by cough, nasal discharges, painful sensations in the throat and sudden vomiting spells.

In addition, dyspnea, cyanosis, a moderate temperature rise and rales in the lungs were observed in gravely ill persons. In medical institutions, there was a sharp increase in cases of persons reporting with an acute affection of the respiratory tract. People reporting heart disease also increased.

Comparison of the disease and mortality rates during the period of the fog with the concentrations of atmospheric pollutants (soot and sulfurous anhydride) showed that the concentrations of soot and sulfurous anhydride during that period were respectively 5 and 6 times as high as the level usually observed in London. The concentrations of sulfurous anhydride amounted to an average of 7-3.5 mg/m^3 during that period.

It was postulated that the increase in the number of fatal cases and illnesses of the respiratory organs during the period of the December fog in 1952 was due to the action of products of incomplete fuel combustion contained in the fog.

Emissions of house furnaces with an inadequate mode of fuel combustion in open fireplaces substantially promoted the pollution of the atmosphere with sulfur oxides and soot.

Cases of substantial atmospheric pollution had been repeatedly observed in London even before the disaster of 1952. Thus, an increase in mortality rate was noted during periods of thick fog in December 1873, January 1880, February 1882, December 1892 [46].

In recent years, five occurrences of increased mortality have been described among the population of New York as a result of a high level of air pollution because of unfavorable meteorological conditions (weak wind and temperature inversion). These cases were recorded in New York in 1962 from 26 January to 6 December*; in 1963, from 30 December to 15 January, from 29 January to 13 February and from 12 April to 25 April; in 1964, from 27 February to 10 March. At the same time, it was noted that an increase in mortality immediately follows the development of heavy air pollution. An increase in mortality was noted among inhabitants of all age groups [48].

The American journal "Time" published a special article entitled "The Poisoned Air of America" [49] which attracted the public's attention. This article cites cases of disastrous air pollution in New York in 1953, when in the course of a 10-day temperature inversion 200 people died; in 1963, during a thick fog (smog), over 400 people died, and 80 other fatal cases were recorded in 1967. The chief cause of the increased mortality in New York as well as Donora and London were sulfur oxides (sulfur dioxide and trioxide).

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* Editor's note: This series of dates should probably be given as from 6 December, 1961 to 26 January, 1962; from 30 December, 1962 to 5 January, 1963; from 29 January to 13 February and from 12 to 25 April, 1963; and in 1964 from 27 February to 10 March.

A sharp rise in the concentration of sulfurous anhydride, from 2 to 4 mg/m^3, is known to have occurred in the Ruhr region during a temperature inversion [51]. The appearance of cough, headache, and, among asthmatics, of dyspnea was observed among the population. A decline in health was noted among nurslings and persons over 45 years of age, and also among those suffering from cardiovascular and lung diseases.

We have dwelt on a description of the principal, common cases of large-scale illness and mortality among the population that took place in certain foreign countries under special weather conditions (anticyclone, temperature inversion, fog) responsible for the formation of a toxic fog with dangerous concentrations of atmospheric pollutants in the ground layer.

Cases of disastrous atmospheric pollution in industrial centers have been observed during periods of windless weather and temperature inversion; the meteorological conditions not only hindered the dispersal of atmospheric pollutants, but also promoted their maximum concentration in the ground layer. The inversions lasted from 3 to 10 days.

The illnesses of the population were characterized by injuries to the respiratory organs and irritation of the muccous membrances of the eyes, nose, pharynx, and respiratory tract. The most sensitive group among the population were nurslings, persons over 40-55 years of age, and those suffering from cardiovascular and lung diseases.

A characteristic feature of all the cases described was an improvement in the health of the victims and a sharp reduction of the disease rate and fatal cases among the population after the fog had dispersed.

The cases described permit one to conclude that in industrial centers and towns with a highly developed industry, under unfavorable meteorological conditions, a heavy surface pollution of atmospheric air with noxious chemicals may occur that is capable of causing an increased disease rate and mortality among the population.

The chief cause of the massive incidence of illness and increased mortality rate among the population in these cities were sulfur oxides.

In discussing the disastrous pollution of atmospheric air in cities, one must not neglect to mention the state of the atmosphere in Los Angeles.

According to the data of medical observations [46], during a smog in Los Angeles there were also observed large numbers of complaints of irritation of the mucous membranes of the eyes, nose and pharynx. A frequently recurring smog worries the city's inhabitants.

The Los Angeles smog has a different character and forms in hot, sunny weather. It is based on photochemical reactions between nitrogen oxides and hydrocarbons (olefins) escaping into the air during the combustion of fuel, especially petroleum products. The maximum concentration of sulfur dioxide during a smog amounts to around 1 mg/m^3, but according to researchers, sulfur dioxide is not an essential ingredient of the air pollutants in Los Angeles.

However, since June 1955, a system of "smoke alerts" has been used in California in view of the frequently recurring smogs; the purpose of this system is to "prevent an excessive accumulation of atmospheric pollutants in order to avoid a disaster caused by 'toxic concentrations'." These alerts are sounded depending on the content of sulfur dioxide, nitrogen oxides, ozone and carbon monoxide in atmospheric air (Table 9) [52].

Table 9

Gas Concentrations for the "Smoke Alert" System

Substance	Maximum Permissible Concentrations					
	Warning		Alerting		Dangerous	
	In Parts per Million	mg/m^3	In Parts per Million	mg/m^3	In Parts per Million	mg/m^3
Nitrogen oxides	3	12,3	5	20,5	10	41,0
Ozone	0,5	1,0	1	2,0	1.5	3,0
Sulfurous anhydride. . . .	3	8,4	5	14	10	28,0
Carbon monoxide	100	123,0	200	246	300	370,0

As is evident from Table 9, the dangerous concentrations characterize the level of atmospheric pollutants constituting a menace to health.

In a sanitary evaluation of the atmospheric pollution of industrial cities, one must note the possibility that dangerous concentrations of noxious chemicals may be produced as a result of accidents or failures in gas purification systems, when considerable amounts of toxic products will immediately escape into the atmosphere in a very short time. Such products combined with unfavorable meteorological conditions may lead to serious acute poisoning of the population even when they act for a short time.

In such cases, a particular danger to the population may be posed by the escape into the atmosphere of hydrogen sulfide, nitrogen oxides, fluorine compounds, chlorine and hydrogen chloride, sulfuric acid fog, ammonia, etc. Such cases also have been described in the literature.

A case in point deserving close attention is the disaster that occurred in 1950 in Posa-Rica (Mexico), when as a result of the escape of a large amount of hydrogen sulfide into the atmosphere during an accident at the gas-producing plant in that town, an acute poisoning of 320 persons was observed, 22 of whom died. The serious situation thus produced was aggravated by a temperature inversion, associated with a slight movement of air. Ten to twenty minutes after the accident, the hydrogen sulfide reached the residential areas of the town and caused serious poisoning. The damage was repaired 20-25 minutes after it took place [46].

This case shows that a large-scale poisoning of the population, even with fatal results, may take place during a very short period of time.

In November 1961, a case was described involving a subacute poisoning of schoolchildren with hydrogen sulfide and sulfur dioxide while they were in the school, which was located in the settlement of the Lacq gas plant (France) [53]. During the gas pollution of atmospheric air with sulfur-containing emissions of the gas plant, the schoolchildren studied while wearing gas masks.

In many countries, cases have been known involving acute poisoning of sensitive people living in the vicinity of synthetic viscose fiber and cellulose plants and petroleum distillation plants. These poisonings were manifested in nausea and mild stomach disturbances and appeared under meteorological conditions that were the most unfavorable for the given area. A description was given of a case involving the explosion at night of a tank containing 15 tons of liquid chlorine, which took place in 1952 in one of the towns of West Germany and caused a large-scale poisoning of the neighboring population with chlorine (over 200 people were affected) [54].

Also known are cases of subacute poisoning of the population residing near chemical complexes and nonferrous metallurgical plants by emissions of sulfuric acid fog into the atmosphere during starting and adjusting operations in connection with the introduction of new sulfuric acid plants and during the adjustment of the sulfur-removal equipment at a sintering plant, in combination with unfavorable meteorological conditions. In these intoxications, the population showed symptoms of marked irritation of the mucous membranes of the eyes and upper respiratory tract (heavy choking cough, chest pain).

Dangerous chlorine concentrations in atmospheric air may also be produced by chlorine-processing enterprises during technological accidents and failures.

In addition to their noxious influence on human health, industrial emissions into the atmosphere cause considerable damage to the national economy. This is expressed in enormous losses of chemical products valuable to the national economy. The waste gases have a fatal effect on forests, orchards, and sown crops, and sometimes cause illness and death among farm animals. According to the data of the Botany Laboratory at Nancy, in 1960, the damage to orchards and forests caused by industrial emissions into the atmosphere, was determined to be 400 million francs in Belgium, 3430 million francs in England, and over 2000 million francs in France. The total material loss due to atmospheric pollution in the U.S.A. in 1950-1951 46 was around $1.5 billion, and a considerable part of this loss was due to crop damage.

It is evident from the above that as a result of industrial emissions, air pollution in modern cities may cause the appearance of high concentrations of toxic substances in the atmosphere. This is particularly possible under unfavorable atmospheric conditions (temperature inversion, calm, low temperature, fog, etc.), which promote the accumulation of pollutants in the ground layer of the atmosphere, causing massive illness and an increased mortality among the population.

Mechanism of Impurity Dispersal in the Atmosphere as a Function of Meteorological Conditions

In the preceding sections we discussed the sanitary aspects of the problem of atmospheric pollution with industrial emissions. In the present section we shall dwell on the physical aspect of this problem.

As we know, any impurity introduced into the atmosphere is dispersed comparatively quickly by turbulent air currents. However, this dispersal proceeds at different rates under different weather conditions.

The dispersal of an impurity depends on two main factors: the wind velocity and the vertical distribution of the air temperature. The greater the wind velocity, the more rapid the dispersal of the impurity. When the wind velocity doubles, the impurity becomes diluted in twice as large a volume of air.

The vertical distribution of the air temperature depends on the degree of heating of the earth's surface and of the layer of air adjacent to it. The more the earth's surface is heated, the more rapid the vertical mixing of air. During the day, under a clear sky, the earth's surface is heated by the sun and in turn heats up the adjacent air. At night, however, under a clear sky, the earth cools because it gives up heat (by radiation), and the air near the earth also cools. Heated air rises because of a decrease in density, and conversely, cooled dense air descends toward the earth's surface.

The vertical temperature distribution is also characterized by the fact that as the density of dry air decreases with increasing height, this air expands adiabatically, and as a result of the expansion cools by approximately 1° for every 100 m of height.

In the presence of a superadiabatic temperature gradient, when the temperature drops faster than 1° per 100 m as the height increases, as is often the case when the earth's surface is heated by the sun, the heated air masses rise to a great height, whereas the cool air currents descend downward relatively quickly. Such weather conditions are termed convective and are characterized by an intensive mixing of air. A constancy of the temperature of an air layer with the height is called isothermy.

If the temperature does not decrease with the height, but rises, the mixing of air is minimal. Such conditions constitute an inversion. The latter takes place near a cooled earth's surface, usually at night during clear weather.

The effect of the temperature gradient on the mixing of a plume is shown in Figs. 1-3.

In convection, a smoke plume descends towards the earth's surface near the smokestack at distances starting at 2-3 stack heights, and for a short time produces substantial concentrations near the earth ("wavy" plume). In isothermy, the plume gradually expands and at a distance of 10-20 stack heights reaches the earth ("conical" plume). In an inversion, the plume moves in a fine thread that remains almost undiluted in the vertical direction, sometimes oscillates like a fan in the horizontal plane, and reaches the ground only at very large distances, i.e., 100-200 and more stack heights ("threadlike" or "fan-shaped" plume).

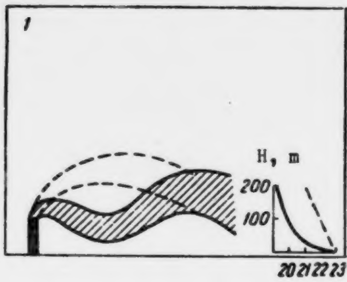
The movements of a smoke plume shown in Figs. 1-3 are characteristic of a stable wind and typical only of basic types of a smoke plume in the atmosphere.

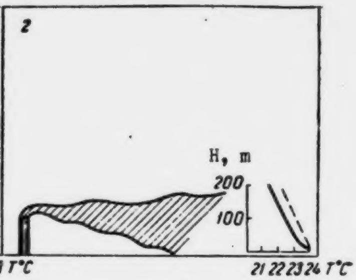
Other types of smoke plumes also exist in the atmosphere during inversions.

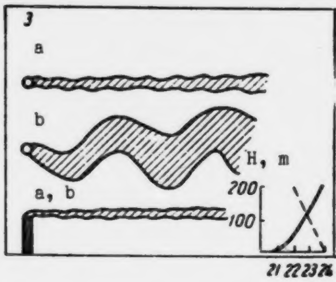
Thus, if an inversion layer is located below the mouth, and air mixing takes place above the stack, the plume becomes rapidly dispersed upward ("elevated" plume, Fig. 4). If the inversion layer is located above the stack, and air mixing takes place below, a "smoking" plume is formed (Fig. 5).

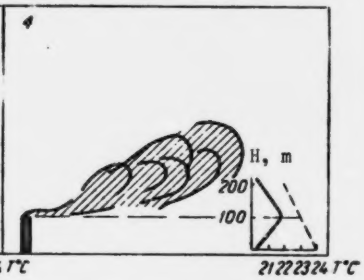
The "smoking" plume usually arises during the transition from nocturnal inversion to diurnal convection, when the earth's surface begins to heat up, and the smoke plume under the inversion canopy mixes with the ground air without being dispersed upward.

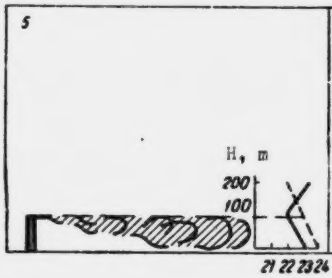
There is still another special form of smoking plume, the so-called "dangerous" plume, which usually arises only during anticyclonal weather and is characterized by very weak winds, calms, and descending air currents. It is in such cases, particularly during the autumn-winter period, that the formation of a stable layer of a deep inversion above the stack, the so-called "roof", becomes possible (Fig. 6).


1
H, m
200
100
20 21 22 23 T°C


2
H, m
200
100
21 22 23 24 T°C


3
a
b
H, m
a, b
200
100
21 22 23 24 T°C


4
H, m
200
100
21 22 23 24 T°C


5
H, m
200
100
21 22 23 24 T°C

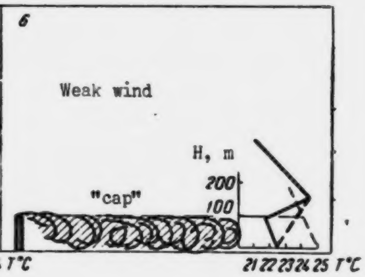

6
Weak wind
H, m
200
"cap"
100
21 22 23 24 25 T°C

Fig. 1. Convection, "wavy" plume

Fig. 3. Inversion
a - "threadlike" plume;
b - "fan-shaped" plume;
a, b - lateral view

Fig. 5. Inversion, "smoking" plume

Fig. 2. Isothermy, "conical" plume

Fig. 4. Inversion, "elevated" plume

Fig. 6. Inversion, "dangerous" plume.

Depending on the nature of atmospheric circulation, the plume is dispersed in different ways.

The appearance of cyclones in the atmosphere is characterized by a vortex rotating counterclockwise in the northern hemisphere and accompanied by a pressure drop, and also with slow and lasting ascending movements of air, resulting in a general rise of the ground masses into the upper layers of the atmosphere with the formation of cloudiness and precipitation. Cyclones are usually accompanied by strong winds. The atmosphere-polluting impurities present in cyclones are rapidly dispersed over a large volume of air, and in addition, rainfall washes part of the impurities out of the atmosphere.

In anticyclones, which are accompanied by a pressure drop, the air flow rotates clockwise in the northern hemisphere and slowly descends toward the earth. As the air sinks, its density increases, while the temperature rises. The effect is increased by the condensation of moisture and liberation of the heat of condensation. All this may lead to the creation of a stable, lasting "cap" above the stack. When there are no vertical movements of the air and no wind, no dispersal of the impurities takes place either. Emission from a smokestack under these conditions may lead to the creation of high, dangerous concentrations near the ground.

We shall examine the methods of calculation of impurity dispersal in the atmosphere.

Atmospheric air is constantly in a state of turbulent movement. The latter consists of a certain average flow (average wind) on which fluctuations* of the velocity and directions of the flow (wind gustiness) are superimposed. The rate of these fluctuations depends substantially on the degree of warming of the air near the surface of the ground. During the day, when the surface is strongly heated, the turbulence is maximum, and at night, when the ground cools, it is minimum. The turbulence also depends substantially on the roughness of the ground surface.

As a result of turbulence, the layers of air are continually being mixed, so that any impurity present in the air is rapidly dispersed. This mixing of air layers may be assumed similar to the process of gas diffusion and, by using appropriate methods for obtaining different solutions of diffusion equations, one can carry out calculations of the distribution of concentrations at all points of space for an impurity coming from different sources: an instantaneous point source or three-dimensional source (a cloud of smoke), a continuous point source (smoke plume from a stack), a continuous linear or surface source (plumes coming from many stacks), etc.

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* Editor's note: Throughout this section the authors use the term "pulsation" instead of fluctuation.

In contrast to molecular diffusion, where the diffusion coefficients are constant, in a turbulent flow they are characterized by a complex dependence on the coordinates, the space or time scale of the diffusion, the meteorological parameters, the state of the surface of the ground, and other factors.

The coefficient of turbulent diffusion in the atmosphere may vary from 0.2 to 10^{12} cm^2/sec. It should be noted that the atmosphere contains eddies of different sizes, from minimum ones determined by the viscosity of air, in which the turbulence energy is converted into heat, to maximum ones, determined by the geometry of the flow, the underlying surface, the thermal stability, etc. The largest eddies, are, for example, cyclones and other air phenomena occupying large portions of the atmosphere. The larger the initial size of the smoke cloud or the longer the time of existence of such a cloud, the higher the probability of its capture by large eddies and of its dispersal. In addition, some constant scale and hence constant diffusion coefficients can be assumed for each specific problem, and the diffusion laws can be used with a constant coefficient for calculations of the dispersal of an impurity in the atmosphere.

At the present time, two theories, called the "statistical" theory and the "diffusional" theory, are used for calculations of turbulent diffusion of impurities in the atmosphere.

Adherents of the first theory have tried to take into account the dependence of the diffusion coefficients on the scale of propagation of the impurity, and adherents of the second theory consider the diffusion over practically acceptable distances to be independent of this scale.

In the "statistical" diffusion theory it is assumed that the probability of transport of particles from one point of space to another is determined by a "probability density" function satisfying the condition:

$$\int_{-\infty}^{+\infty} \psi(x, y, z)\, dx dy dz = 1 \qquad (1)$$

Assuming that the "probability density" function ψ is described by the Gauss distribution formula, we write the latter for a homogeneous medium:

$$\psi(x, y, z) = \frac{\overline{\sigma}^3}{\pi^{3/2}} e^{-(x^2+y^2+z^2)\overline{\sigma^2}} \qquad (2)$$

where σ is the dispersion parameter.

The dispersion parameter is related to the mean square deviation of the particles $\overline{y^2}$ as follows:

$$\overline{y^2} = \frac{1}{2\overline{\sigma^2}} \qquad (3)$$

It follows that in a homogeneous (isotropic) medium, the concentration of particles at any point of space from an instantaneous point source will be:

$$c(x, y, z) = Q_0 \left[\frac{1}{(2\pi \overline{y^2})^{3/2}} e^{-\frac{x^2+y^2+z^2}{2\overline{y^2}}} \right] \qquad (4)$$

where Q_0 is the initial number of particles.

The mean square of the dispersion is the basic characteristic of the dispersal of particles and of the rate of their diffusion.

Taylor [55] showed that in the presence of homogeneous turbulence, the degree of dispersal of particles depends on the distribution of wind velocity fluctuations according to the formula:

$$\overline{y^2} = 2\overline{(u')^2} \int_0^t d\tau \int_0^\tau R(s)\, ds \qquad (5)$$

where R(s) is the Lagrangian correlation scale and $(\overline{u}')^2$ are the mean square fluctuations of the wind velocity in the direction of the x axis.

The value R is determined from the ratio of the mean square wind fluctuations at times t and $t+\xi$

$$R = \frac{\overline{u'(t) \cdot u'(t+\xi)}}{\overline{(u')^2}} \qquad (6)$$

From dimensionality considerations, O. F. Setton [56] assumed the following expression for R:

$$R = \left[\frac{\nu}{\nu + \overline{(u')^2}\xi} \right]^n \qquad (7)$$

where ν is the kinematic viscosity of air and n is a number varying from 0 to 1.

The value n is determined from the wind velocity distribution at two heights:

$$\frac{u_z}{u_1} = \left(\frac{z}{z_1} \right)^{\frac{n}{2-n}} \qquad (8)$$

In strong convection n is close to zero, in isothermy n = 0.25, and in a deep inversion n = 0.5.

Substituting (7) and (8) into (5) and (4) and integrating with respect to time, Setton obtained a formula permitting the calculation of the concentration for a continuous point source:

$$c(x, y, z) = \frac{2Q_0}{\pi s_y s_z \bar{u}_1 x^{2-n}} e^{-x^{n-2}\left(\frac{y^2}{s_y} + \frac{z^2}{s_z}\right)} \tag{9}$$

where x is the wind distance; $\bar{u}$ is the average wind velocity, and s_y and s_z are the virtual diffusion coefficients.

The coefficient 2 allows for the reflection of the plume from the surface of the ground.

The values

$$\begin{aligned} s_y &= \frac{4v^n}{(1-n)(2-n)\bar{u}^n}\left[\frac{(v')^2}{\bar{u}^2}\right]^{2-n} \\ s_z &= \frac{4v^n}{(1-n)(2-n)\bar{u}^n}\left[\frac{(w')^2}{\bar{u}^2}\right]^{2-n} \end{aligned} \tag{10}$$

where v' and w are the wind fluctuations along axes y and z.

It was found that at a height above 25 m, $s_y = s_z = s$.

The maximum concentration near the ground from a continuous source located at height H (c_{max}) and the distance at which it is reached (x_{max}) are determined from the formulas

$$c_{max} = \frac{2Q_0}{e\pi \bar{u}_1 H_{eff}^2} \tag{11}$$

$$x_{max} = \frac{H_{eff}^2}{S^2} \tag{12}$$

Using the experimental data, one can take $s_y = s_z = 0.05$ and $n \simeq 0$. Then the Setton formulas for estimated calculations of the concentration during the emission of noxious substances from the stacks assume the form:

$$c_{max} = \frac{0,235Q_0}{\bar{u}_1 H_{eff}^2} \tag{13}$$

$$x_{max} = 20H_{eff} \tag{14}$$

It should be recalled that the quantity H_{eff} entering into this formula is the effective height of the source, i.e., a sum composed of the geometric height of the stack and the height of ascent of the smoke plume due to the velocity factor and the thermal factor.

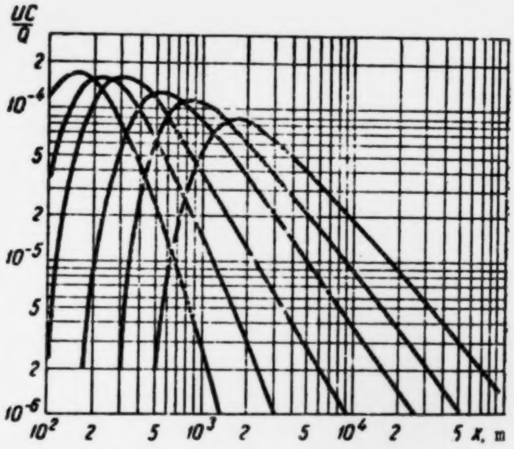

Fig. 7. Distribution of relative concentration values for stacks 30 m high.

The Setton formulas have been checked by a number of authors and although in general these formulas correctly express the qualitative character of dispersal of impurities in the atmosphere, they fail to take into account or incorrectly describe some very important aspects of the process of diffusion of impurities in the ground layer of the atmosphere; for example, they incorrectly consider the dependence of the vertical diffusion coefficient on the height above the surface of the ground, yield too low a value of the horizontal diffusion coefficient, etc.

On close inspection, the Setton formulas showed a substantial divergence with the experiment, and they are now regarded as extrapolation formulas applicable only to the conditions of Setton's experiments.

The Setton formulas had been applied in this country to calculations of diffusion of impurities by Ye. N. Teverovskiy [57] and P. I. Andreyev [58]. The latter gave practical recommendations for the application of Setton formulas to the calculation of smokestacks, and these recommendations have been applied for a number of years.

The calculation of the stacks was carried out chiefly by using formula (13), provided that the highest concentration was equal to the maximum permissible concentration established by sanitary authorities.

Figures 7 and 8 show the distribution of relative concentration values for a unit discharge (1 g/sec) and unit wind (1 m/sec), calculated from Setton formulas for stacks 30 and 100 m high [59].

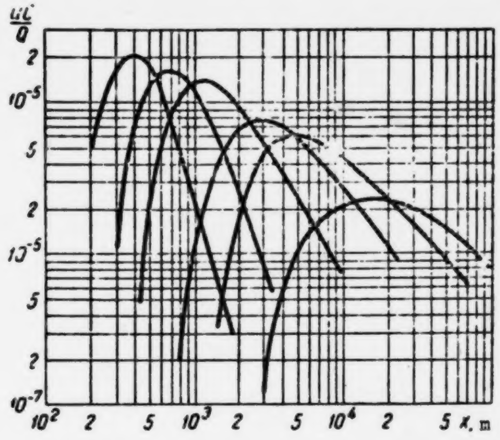

Fig. 8. Distribution of relative concentration values above stacks 100 m high.

Both the Setton formulas and the curves of Figs. 7 and 8 pertain to determinations of the "instantaneous" concentration in 2-3 minutes. For a longer sampling time, the measured concentrations turn out to be substantially below the calculated ones.

A different solution of the problem of impurity dispersal was obtained by D. L. Laykhtman in 1940-1945 [60], who took diffusion coefficients independent of the averaging time for certain distances (up to 10 km) and gave a relatively rigorous description of the increase of the wind velocity and coefficient of vertical diffusion with the height. This solution is in accord with the diffusion theory.

In this case, the height distribution of the wind velocity is expressed by the following formula, which is borne out experimentally:

$$\frac{u_z}{u_1} = \frac{z^{\varepsilon} - z_0^{\varepsilon}}{z_1^{\varepsilon} - z_0^{\varepsilon}} \tag{15}$$

The vertical and horizontal diffusion coefficients assume the form:

$$k_z = k_1 \left(\frac{z}{z_1}\right)^{1-\varepsilon} \tag{16}$$

$$k_y = k_0 u_1 \left(\frac{z}{z_1}\right)^{\varepsilon_1} \tag{17}$$

where z_0 is the average roughness of the area; ε and ε_1 are parameters dependent on the temperature gradient.

u_1 and k are the wind velocity and coefficient of vertical diffusion at height z_1 (usually $z_1 = 1$ m); k_o is a constant.

The parameters entering into formulas (15) and (17) were obtained from the experimental data.

a) $k_o = 0.65$

b) $\varepsilon = -0.2\Delta t$; $\Delta t = t_{1.4} - t_{13.4}$

(Δt is the temperature difference at heights of 1.4 and 13.4 m);

$\varepsilon=0$ - isothermy ($\Delta t = 0$);
$\varepsilon<0$ - convection ($\Delta t>0$);
$\varepsilon>0$ - inversion ($\Delta t<0$);

c) the dependence of K_1 on ε for $-0.5\leqslant\varepsilon\leqslant0.2$ is expressed by the following empirical formula:

$$k_1 = \frac{0.15\,|\,\varepsilon\,|\,z_0^{2\varepsilon}}{(1-\varepsilon^2)(1-z_0)}\,u_1 \tag{18}$$

where z_o is the generalized roughness

$$z_0 = z_{00} - 0.2\varepsilon \tag{19}$$

z_{oo} is the dynamic roughness in isothermy

$$(\Delta t = 0;\ \varepsilon = 0)$$

d) the values of parameter ε are given in Table 10.

Table 10

Values of ε and Corresponding Values of ε_1, K_1 and α for an Open Level Area Covered with Grass of Moderate Height (z_o from 0.04 to 0.05 m)

Convection		Isothermy	Inversion	
ε −0,2	−0,1	0,0	0,1	0,2
ε_1 0,13	0,14	0,15	0,17	0,19
K_1 0,09	0,07	0,05	0,015	0,005
α 0,72	1,6	1,5	1,43	1,36

For calculations of the concentration near the ground at the axis of the plume, the following formulas may be used:

$$c(x, y, 0, H) = \frac{Q_0}{u_1} B . x^{-\alpha} e^{-\frac{A}{x}} \qquad (20)$$

$$\alpha = \frac{3}{2} - \frac{\varepsilon}{1 + \varepsilon + \varepsilon_1}$$

$$A = \frac{H^{1+\varepsilon+\varepsilon_1}}{k_1 (1 + \varepsilon + \varepsilon_1)}$$

$$B = \frac{1}{2,86\, \Gamma\left(\frac{1+\varepsilon_1}{1+\varepsilon+\varepsilon_1}\right) k_1^{\frac{1+\varepsilon}{1+\varepsilon+\varepsilon_1}} \cdot (1 + \varepsilon + \varepsilon_1)^{\frac{1+\varepsilon-\varepsilon_1}{1+\varepsilon+\varepsilon_1}}}$$

Γ is the symbol of the gamma function.

The maximum concentration near the ground (c_{max}) and the distance from the stack to the point on the ground where the concentration is maximum (x_{max}) are calculated from the formulas

$$c_{\text{макс}} = \frac{Q_0}{u_1} \frac{B}{(e x_{\text{макс}})^{\alpha}} \qquad (21)$$

$$x_{\text{макс}} = \frac{A}{\alpha} \qquad (22)$$

The Laykhtman formula describes the diffusion of the impurity at a distance of up to 10 km under different meteorological conditions much more accurately than the Setton formulas.

Attempts to perfect these formulas [61] and allow for the dependence of the diffusion coefficients on the space and time scales have not given any substantial results thus far, despite considerable mathematical complications of the theory.

R. Pasquille [62] proposed a method of calculating the distribution of an impurity that is particularly convenient for single discharges from stacks (for example, in an accident). For a continuous discharge, his formula has the following form:

$$c = \frac{0,168 Q_0}{u x \theta h} \qquad (23)$$

where c is the concentration at the axis of the cloud; Q_o is the discharge per unit time; U is the wind velocity; Θ is the aperture angle of the jet, and h is the height of the cloud.

The author devoted special attention to the determination of the dependence of Θ and h on the meteorological conditions. When these values are appropriately selected, the concentration can be evaluated with practically any acceptable accuracy.

However, even formula (23), which permits the evaluation of the concentration at a distance of up to 100 km, does not allow for the dependence on the averaging time.

In recent years, at the Main Geophysical Observatory under the supervision of M. Ye. Berlyand, theoretical and experimental studies were conducted on the distribution of the concentration of impurities discharged from plant stacks [63].

The problem of impurity diffusion was examined with the same assumptions as those of D. L. Laykhtman, but in this case a computer was used to make an exhaustive study of the solution obtained [63].

The highest concentration near the ground was

$$c_{\max} = \frac{aQ_0}{uH_{\text{eff}}^{b}} \tag{24}$$

Here a and b are coefficients obtained in a numerical solution of the problem. If U_1 is the wind velocity at a height of 1 m, then for a stack with $H_{\text{eff}} = 100$ m, the quantities $a \approx \sqrt{\frac{k_1}{k_0 u_1}}$ and $b = 1.8$.

The distribution of the ground concentration of a weightless impurity for $k_2 = k_1 z$ and $u = u_1 z^n$ is expressed by the formula:

$$c = \frac{Q_0}{2(1+n)k_1\sqrt{\pi k_0}\,x^{1.5}}\,e^{-\frac{uH^{n+1}}{k_1(1+n^2)x}-\frac{y}{4k_0x}} \tag{25}$$

The value of the highest concentration is expressed by the formula:

$$c_{\max} = \frac{0.116(1+n)^2 Q_0}{u_1 H^{1.5(1+n)}}\sqrt{\frac{k_1}{k_0 u_1}} \tag{26}$$

The distance at which the highest concentration is reached will be expressed by the formula:

$$x_{\max} = \frac{2}{3}\,\frac{n_1 H^{1-n}}{k_1(1+n)^2} \tag{27}$$

Consideration of the "time of concentration averaging" was very essential.

As already noted, the Setton and Laykhtman formulas pertain to a 2-3 minute averaging interval, i.e., to the determination of the "instantaneous" concentration.

The so-called single concentration for 20-30 minutes is standardized by sanitary rules. It has been established experimentally that as the assortment of samples increases, the concentration decreases, this being explained by wind direction fluctuations, the probability of the increase of which increases with time. The coefficient of horizontal diffusion apparently increases with time and can be written as:

$$k_0 = \frac{1}{2} x\varphi_0^2 = \frac{1}{2} ut\varphi_0^2 \tag{28}$$

where ϕ_0^2 is the mean square variance of the angle of rotation of the wind.

Substituting k_1 for k_0 in equation (25), after finding the maximum we obtain the following formulas:

$$c_{\max} = \frac{0,216k_1 (1 + n)^3 Q_0}{\varphi_0 u_1^2 H^{2(1+n)}} \tag{29}$$

$$x_{\max} = \frac{u_1 H^{1+n}}{2\, k_1 (1 + n)^2} \tag{30}$$

Calculation showed that the single concentration is approximately one-half the "instantaneous" concentration.

Of great importance also was the derivation of sufficiently accurate formulas for calculating the thermal ascent of a plume discharged from plant stacks:

$$\Delta H = \frac{1,5w_0R_0}{u} \left(2,5 + \frac{3,3gR_0\Delta T}{T_0u^2}\right) \tag{31}$$

where w_0 is the gas exit velocity from the stack; R_0 is the radius of the stack mouth; u is the wind velocity at the height of the stack mouth; g is the acceleration due to gravity; ΔT is the difference between the temperature of the escaping gases and the air temperature at the height of the stack mouth.

In addition, the influence of heavy suspended aerosol particles on the distribution of the concentration was studied. It was shown that the settling particles produce greater concentrations on the ground near the stack and in the zone of the maximum than the weightless impurity does. On the contrary, far from the stack, the concentration may become lower than that produced by the weightless impurity.

In selecting the necessary height of the smokestack, all the working parameters should be chosen so that the single concentration (for 20-30 minutes) of the noxious impurity does not exceed the maximum permissible concentrations for any meteorological conditions.

Hence, the diffusion coefficients should be taken for the highest values of c_{max}. In addition, it is necessary to select correctly the calculated wind velocity. According to all the diffusion formulas, the concentration increases in inverse proportion to the wind velocity, i.e., the lower the latter, the higher the concentration. Moreover, the thermal and velocity ascent of the smoke plume is greater the lower the wind velocity, and therefore as the latter decreases, the effective stack height increases and the concentration diminishes.

It follows that at a certain "dangerous" wind velocity the highest concentration of the impurity near the ground is produced:

$$c_{max} = \frac{0.65 k_1 Q_0}{\varphi_0 u_1 H^2 \sqrt{w_0 R_0 \Delta T}\left(1{,}17 + 3{,}7\sqrt{\frac{w_0^2 R_0}{H^2 \Delta T}}\right)^{2.3}} \quad (32)$$

For stacks with a height of over 30 m, with overheating of the gases above 10°:

$$c_{max} = \frac{AmQ_0}{H^2 \sqrt{V \Delta T}} \quad (33)$$

where $V = \pi R_0^2 W_0$ is the volume of gases discharged from the stack in m^3/sec, and m is a coefficient allowing for the velocity of the gas discharges from the stacks:

at $W_0 = 10$ m/sec, $m = 1$;

at $W_0 = 20$ m/sec, $m = 0.9$;

at $W \geqslant 20$ m/sec, $m = 0.8$.

The coefficient A, dependent on the diffusion rate, is essentially related to the climatic conditions. Therefore, on the basis of a detailed analysis, three values of A were taken:

$A_1 = 0.12$ for the middle belt of the European territory of the USSR;

$A_2 = 0.16$ for the north, northwest, the Urals and the Ukraine;

$A_1 = 0.2$ for Kazakhstan, Central Asia, and Central Siberia.

The dangerous wind velocity at the height of the wind vane (10 m), u_d, at which the largest values of the maximum concentration are reached, is:

$$u_d = 0{,}65 \sqrt[3]{\frac{V \Delta T}{H}} \quad (34)$$

Calculations showed that the ratio $\frac{C}{C_{max}}$ depends only on $\frac{X}{X_{max}}$.

Figure 9 illustrates this dependence.

In 1963, the State Committee on Coordination of Scientific Research Studies ratified for the first time in the USSR a "temporary method for calculating the smokestacks of thermal electric power plants", the working formulas of which are given above [64].

Under certain meteorological conditions - weak winds and a deep inversion layer above the stack ("cap") - a so-called smoking or dangerous plume may be formed.

The concentrations of impurities in such a plume cannot be calculated from the usual diffusion formulas. A calculation of a "smoking" plume was made in one of the studies [65].

Let us consider a case in which the plume of impurity in the presence of an inversion above the stack mouth is uniformly mixed with air in the ground layer as a result of convection that started near the ground. In this case:

$$c = \frac{Q_0}{\sqrt{2\pi}\, s_y u_1 H x^{\frac{2-n}{2}}} \tag{35}$$

Assuming that in an inversion $C_y = 0.5$ and $n = 0.5$, we find that for a "smoking" plume:

$$c = \frac{8Q_0}{u_1 H x^{0.75}} \tag{36}$$

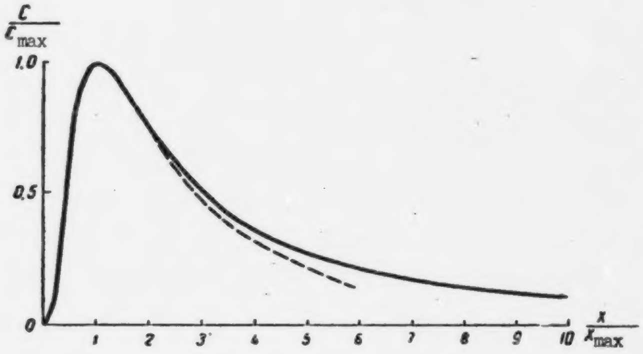

Fig. 9. Dependence of $\frac{c}{c_{max}}$ on $\frac{x}{x_{max}}$.

For a "dangerous" plume, when above the stack mouth in anticyclonal weather and in a very weak wind there is formed a thick inversion layer with a temperature drop of 7-10°, the accumulation of the discharged impurity near the stack without any appreciable dispersal and the descent of this impurity toward the ground with the formation of very high concentrations are possible. Observations carried out in the U.S.A. on a 100-meter smokestack showed that under such conditions, the concentration was an average of 20 times greater than the calculated highest single concentration.

M. Ye. Berlyand [66] studied dangerous conditions of pollution of the atmosphere with industrial emissions. He discussed the influence of an inversion layer above the stack ("cap") on the thermal ascent of a plume emitted from a stack and showed that under these conditions, as a result of a decrease in the thermal ascent of the plume, the maximum concentration may be doubled.

However, under certain conditions (strong inversion above the stack, slightly heated impurity), the ascent of the jet may be limited independently of the wind velocity, and therefore at low wind velocities the concentrations near the ground may increase 5-10-fold.

These estimates give an approximately 10-fold concentration increase over the normal value. Obviously, the accumulation and "tumbling down" of the impurity cloud toward the ground may also produce considerably greater concentrations, i.e., 20 or more times as great as the calculated ones.

This problem has not been sufficiently studied thus far. The probability of such conditions is low, but cases of dangerous smoke pollution are found in almost all countries.

Case of a Smog that Resulted in a Large-Scale Mild Poisoning of the Population

This section will describe a case of large-scale poisoning of the population of an industrial town as a result of pollution of atmospheric air in the presence of a temperature inversion.

On the day when the poisoning occurred, the morning was still, foggy and cold. The air temperature was -21°C. The fog blanketed the ground. The trees were covered with a thick layer of blue hoarfrost. On that day, from 10:30 A.M. to 12 noon, people working in the open air at various locations or those who had walked along the town's streets began to arrive in the clinics of the town and health departments of plants to seek medical help, with complaints of an acute irritation of the upper respiratory tract, tickling in the throat, dry cough, and chest pains.

In the course of the next few hours, the town's medical institutions recorded and examined hundreds of people from the town's territory who suffered from the above-indicated subjective disturbances during that period. In addition to these symptoms, some of the patients complained of an increased salivation and dyspnea. In addition to the above-indicated symptoms, a small number of people had numbness of the tongue and lips, and vomiting, which occurred most frequently at the height of violent coughing spells. By the end of the day, the number of persons who came for help had reached a considerable figure, which led to the assumption of a possible large-scale poisoning of the population caused by pollution of the open air.

Since it was not possible to establish the cause of the large-scale poisoning immediately, the decision was made to hospitalize at once all persons who showed symptoms of poisoning, including those who had suffered even the slightest changes in the way they felt during these hours. To achieve a full hospitalization of the victims, in addition to the inpatient medical institutions, use was made of the dispensaries of industrial plants, from which the patients resting there were quickly discharged.

In a most thorough survey of the victims, 13% of those questioned told of the appearance of some odor during this time interval, but the description of the odor was quite varied ("indefinite", "slight", "odor of burning", "odor of smoke", "odor of petroleum", "insecticide odor", etc.).

The first subjective sensations of the patients were arranged in the following order according to frequency (Table 11).

Table 11

Frequency (in Percent) of First Complaints of Persons Seeking Help

Complaints	Frequency in %
Tickling in the throat, sneezing	90,0
Burning sensation under breastbone	79,0
Dyspnea	76,0
Dry cough	71,2
Chest pains	63,0
Increased salivation	36,9
Nausea, vomiting	30,4
Perception of some odor	13,0

In a mass medical examination of the victims 3-6 hours after the poisoning, most of them complained of tickling and unpleasant sensations in the nose and throat, burning under the breastbone, dry cough, general weakness, dizziness, headache, and nausea.

In an objective study, the majority of the victims at that time showed paleness, slight cyanosis of the lips, isolated, less often multiple dry rales in the lungs, and lability of heart action.

Frequent symptoms were a muffling of the cardiac tones and a tendency toward vascular hypertension (arterial pressure 130/90-150/90 mm Hg).

Physical examination did not show any changes in the digestive organs or urogenital system.

Neurologically, those most seriously affected showed moderate neurocirculatory disturbances manifested in headache, dizziness, and lability of vasomotor reactions.

The clinical picture of massive inhalational poisoning of the population was thus expressed predominantly in an acute irritation of the upper respiratory tract in the form of an acute catarrhal rhino-pharyngolaryngotracheitis.

A day later, the subjective state of the majority of the victims improved: the tickling in the throat and burning under the breastbone decreased, and the coughing stopped. However, symptoms of general weakness and dull headache were mentioned by many.

Some of the victims with the most pronounced symptoms of irritation of the upper respiratory tract were examined by an otolaryngologist.

It was noted that in the majority of the persons studied, a day after the exposure there remained a pronounced hyperemia of the nasal mucosa, soft palate, uvula, palatine arches, tonsils, larynx and trachea, and rear wall of the pharynx. The secretion of mucus was insignificant, and in some of the patients the mucous membranes were dry. In one-half of the victims the nose was stuffy, and the mucous membranes swelled with a bluish-whitish hue. There was a transparent mucus in the nasal passages. Thus, one day after the exposure, the symptoms of acute catarrhal rhino-pharyngo-laryngotracheitis remained. In isolated cases, symptoms of a mild acute bronchitis were observed.

The general condition of the subjects was completely satisfactory. There was not a single case of aggravation of the condition or reinforcement of the intoxication symptoms. Approximately one-half of the victims felt better already next day, and in the remaining ones the symptoms of general intoxication were very mild.

Two days after the exposure, an inpatient examination showed the condition of all the subjects to be fully satisfactory; 44.4% of those hospitalized did not voice any complaints, whereas among the remaining ones, the most frequent complaints were headache and dizziness (31.8%), chest pains (13.0%), and dry cough (8.6%). Hyperemia of the mucous membrances of the respiratory tract was moderately expressed and was noted in 32.7% of the subjects. Hyperemia of the conjunctiva was noted in only 1% of the patients (Table 12).

A roentgenoscopic examination of all the patients failed to show even a single case of any symptoms of acute lung pathology. By that time, the danger of pulmonary edema developing had already passed, so that of the total number of hospitalized persons it was possible to discharge 8%, in whom by that time both subjective and objective symptoms of injury had completely disappeared. Three days after the exposure, 66.7% of those present in the hospital did not voice any complaints.

Table 12

Frequency of Symptoms of Poisoning (in Percent)
2-3 Days After Exposure

Symptoms of Poisoning	On Second Day	On Third Day
Subjective State		
Tickling in the throat	6,9	2,3
Burning behind the sternum	1,0	—
Dyspnea	1,2	—
Dry cough	8,6	6,5
Chest pains	13,0	4,1
Increased salivation	—	—
Nausea	2,0	1,0
General weakness	6,8	3,2
Headache and dizziness	31,8	19,0
Pains in the region of the heart	5,0	1,5
No complaints	44,4	66,7
Objective Symptoms		
Hyperemia of mucous membranes	32,7	11,2
Hyperemia of conjunctiva	1,0	—

The subjective condition of the remaining patients improved considerably: the most frequent complaint was headache (19%), but it was not strong, not significant, and did not have any appreciable effect on the way the patients felt (Table 12).

By that time, the symptoms of irritation of the mucous membranes of the upper respiratory tract in the form of a light hyperemia of these membranes was observed in only 11.2% of the number of patients present in the hospital.

Physical examination of the lungs did not show any pathology: the scattered dry rales noted in the lungs of a few patients disappeared completely three days after the exposure.

No changes whatever were found in the cardiovascular system and gastrointestinal tract that could have been attributed to the toxic effect. Changes in pulse rate and arterial pressure and an increase in the size of the liver and soreness in the right subcostal region were noted in only a few persons who had suffered for years from chronic illnesses.

No deviations were observed in the peripheral blood either. Thus, eosinophilia was found in only 3.5% of the subjects. Changes in the number of leucocytes and in the erythrocyte sedimentation rate were observed only in persons with chronic tonsillitis, sinusitis, chronic hepatocholecystitis, adnexitis, etc.

Analysis of the blood for methemoglobin was negative in all cases. For this reason, three days after the exposure, another 70.2% of the patients were discharged in a state of complete clinical cure, and after four days, another 11.2% were discharged.

Thus, five days after the exposure, 89.4% of those affected had completely recovered and only 10.6% of the hospitalized persons were kept for further observation and treatment in the hospital because they had chronic general diseases: 3% of the patients with hypertensive disease and symptoms of general atherosclerosis showed a certain decline in the way they felt (increase of headache) and were kept in the hospital for treatment.

In 3% of the subjects, an aggravation of their earlier gastrointestinal disturbances (gastritis, hepatocholecystitis) was observed; they complained of increased pains in the epigastric region and in the right subcostal region, and an increased nausea after the intoxication.

In 2.3% of the subjects in the hospital, a typical picture of acute infectious (seasonal) cold of the upper respiratory tract was observed, and one subject showed an aggravation of chronic bronchitis. In 1.3% of the subjects, the vegetative-vascular disturbances which they had had earlier became somewhat intensified.

All the individuals who sought medical help were given oxygen, alkaline inhalations, and symptomatic medicines to reduce the cough and eliminate the headache.

In persons who did not turn to a physician immediately after the exposure, the symptoms of irritation of the upper respiratory tract subsided without treatment during the first 1-2 days.

A commission was formed to investigate the causes of the large-scale poisoning of people.

In order to establish the causes of the poisoning, a thorough technical and engineering study was made on the industrial plants located in the area involved. The study was carried out by checking the technological processes, inspecting the work areas, verifying the technical and technological documents, and interrogating the operators directly. During the inspection of the industrial plants, particular attention was given to the presence of emergency situations and to the disruption of technological processes on the day of the incident.

The inspection showed that the plants located in the region of the accident had been operating under normal technological conditions and had not changed the nature or rate of their production.

There were no cases of emergency situations or disruption of technological conditions in the handling of chemical substances. An inspection of the stocking management of chemicals in the plants and a check of the operations involved in receiving and delivery showed that the transportation, receiving, storage, delivery, utilization and inventory of corrosive and poisonous chemicals were carried out in accordance with regulation requirements.

In order to explain the possible effect of chemicals transported by railroad, a check was made on the railroad tank cars and trains (convoys) moving along the railroad track passing near the town. In view of the absence of cases of poisoning among persons working in the immediate vicinity of the railroad and at neighboring stations, the commission came to the conclusion that railroad transport could not have been the cause of the poisoning.

In addition to the inspection of industrial facilities, the boiler enterprises of the town were also examined. The examination established that because of a sharp drop of air temperature and a shortage of gas fuel on the day of the occurrence, three boiler houses of industrial plants separated by a distance of 800-1000 m from one another operated at full capacity and used high-sulfur mazut as the fuel. The daily consumption of mazut was 204 tons, with an average sulfur content of 3.6%. The emission of sulfur dioxide by all the boiler houses was as high as 600 kg/hour (14,400 kg/day). The flue gases were discharged through stacks 30-40 m high.

Simultaneously with the technical and engineering inspection of the plants, laboratory studies were made on the environment (atmospheric air, snow, clothing of the victims, etc.) in order to identify the chemical agent that caused the large-scale poisoning.

Laboratory studies of objects in the external environment involved all the ingredients which could have produced dangerous concentrations in atmospheric air. Samples of atmospheric air were collected in places where the people were exposed on the day of the occurrence and in the next 2-3 days.

Analyses of atmospheric air for the chemicals used in the technological processes on the day of the occurrence showed the absence of concentration in excess of the maximum permissible values.

Of interest were the analyses of fresh snow. Results of analysis of snow collected at a depth of 4 cm showed an increased content of sulfur oxides (sulfates + sulfites), whose amount considerably exceeded (by a factor of 10 or more) the content of other substances (nitrates, nitrites, chlorides, etc.). In addition, the content of sulfur compounds in snow samples collected in the area of exposure was approximately 6-7 times as high as the content of sulfur compounds in snow samples collected in the control area.

A second analysis of 52 snow samples collected at two levels (at a depth of up to 15 cm and from 15 cm to the ground) showed that in 7-8 days, the pollution of snow with sulfates because of precipitation exceeded (by a factor of 3-4) the pollution of snow that fell in other weeks of the winter season (Table 13).

According to the data of the Hydrometeorological Center of the USSR, the meteorological situation in this region was characterized by anticyclonal, fair, cool weather with weak winds and the formation of fog and heavy hoarfrost. An intense cooling of the ground layer of air during the night led to the formation of a thick temperature inversion layer near the ground with a height of the barrier layer of up to 50 m, which promoted the pressing and concentration of the stream of flue gases.

According to the data of weather stations located nearby, a weak western and northwestern wind was observed during the night, then after 9 P.M., the wind began to turn in the southwestern and southern direction. Table 13 lists data on the direction and velocity of the wind from 0 to 15 hours, [i.e., 12 midnight to 3 P.M.].

Table 13

Velocity and Direction of the Wind

Time (in Hours)	Wind Direction	Wind Velocity (in m/sec)
0.00	Western (250°)	2
1.00	Western (270°)	1
2.00	Western (271°)	1
3.00	Western (260°)	2
4.00	Western (250°)	2
5.00	Western (270°)	2
6.00	Western (270°)	3
7.00	Northwestern (290°)	2
8.00	Northwestern (290°)	2
9.00	Northwestern (290°)	2
10.00	Southwestern (240°)	1
11.00	Southern (190°)	3
12.00	Southern (180°)	1
13.00	Calm	—
14.00	Calm	—
15.00	Southern (180°)	2

At one of the weather stations located nearby, radiosondes were used to measure the temperature distribution in the lower layers of air (Table 14).

Table 14

Temperature Distribution in °C with Height
(From Radiosonde Data)

Height (in m)	Time of Measurements (in Hours)	
	9.00	15.00
Ground	—21,5	—18,0
300	—20,0	—
400	—14,0	—18,0
800	—	—13,0
1 000	—13,0	—
1 500	—15,0	—18,0

The lowest position of the inversion layer was observed at 9 A.M. The temperature drop in the 0-400 m layer was 7.5°C.

More detailed data on the temperature distribution according to height were obtained on a meteorological mast at a distance of about 100 km from the area where the smoke pollution occurred.

These data are shown in Fig. 10. As is evident from the latter, at 9:30-10 A.M., at a height of about 40 m, an inversion layer was formed with a temperature drop of 6-7°C., which formed a "cap" above the low smokestacks of the local boiler houses, which burned sulfur mazut with an average sulfur content of 3.6%.

As was noted above, all three boiler houses, separated by distances of about 800-1000 m, burned 204 tons of mazut.

Let us first calculate the emission of sulfur oxides by boiler house No. 1:

$$Q_{\text{sulfur}} = \frac{95 \times 10^6 \times 3,6}{24 \times 3600 \times 100} = 40 \text{ g/sec}$$

$$Q_{SO_2} = 40 \times 2 = 80 \text{g/sec}$$

We shall calculate the highest single concentration from the formula for a stack height of 40 m and a wind velocity of 2 m/sec:

$$C_{\max} = \frac{235 \times 80}{2 \times 2 \times 40^2} = 3 \, \text{mg/m}^2$$

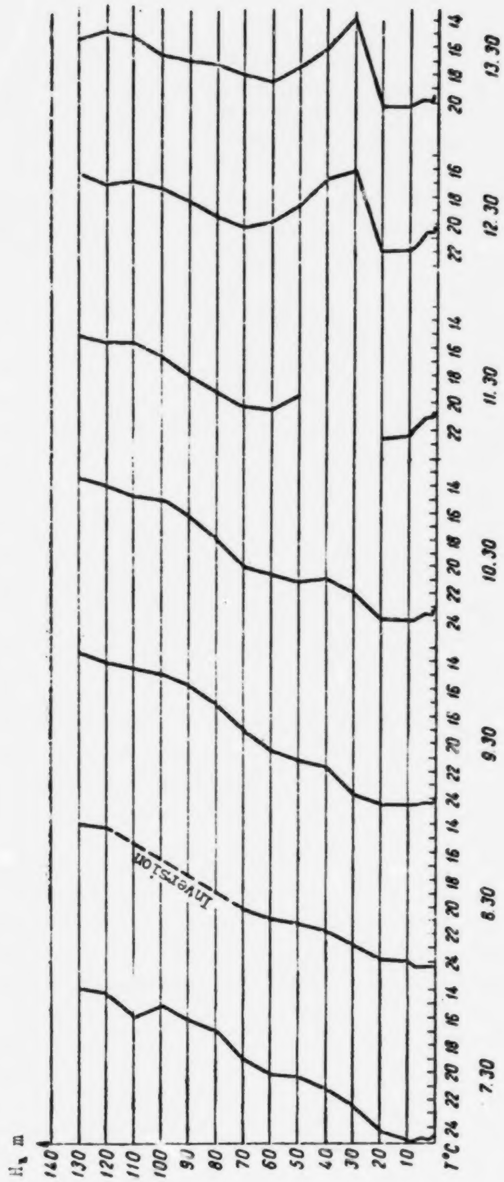

Fig. 10. Distribution of temperature according to height.

Calculations of the emission of sulfur dioxide into the atmosphere made it possible to determine the highest concentrations which can be produced at a distance of 10-20 H or 400-800 m from the boiler house stacks.

The highest concentration of sulfur dioxide discharged with the flue gases by the most powerful boiler house is shown by the calculations to be 3 mg/m^3, which is 6 times as high as the maximum permissible concentration for atmospheric air of populated areas.

For the remaining two boiler houses, the highest concentrations could be respectively 3-4.5 times as high as the maximum permissible concentration.

Consequently, in the combustion of sulfur mazut, all the indicated three boiler houses produced a considerable excess over the maximum permissible concentration, since they had low stacks.

In the case of a "dangerous" smoking plume, the concentrations of sulfur dioxide in the ground layer could have been substantially greater, as is evident from the calculation made by using the formula.

From formula (36), assuming a height of the barrier inversion layer H = 40 m and a distance of 500 m from the stack, we obtain for boiler house No. 1

$$C_{\text{smoke}} = \frac{8 \times 80 \times 1000}{2 \times 40 \times 500 \times 0.75} = 80 \text{ mg/m}^3$$

Considering the possibility of a combination of the smoke plumes from all three boiler houses, the highest sulfur dioxide concentration could have reached 100 mg/m^3, which is 2-3 times the sulfur dioxide concentration for which an acute injury of the upper respiratory tract is observed.

The largest concentration could have been produced in low areas, where the flue gas ascended in the presence of the prevailing weak wind, which was close to a calm. A sulfur dioxide concentration equal to 100 mg/m^3 is approximately 20 times the ordinary concentration produced under average meteorological conditions and 200 times the maximum permissible value.

It was noted that injury to people in different parts of the area agreed in time with the change in the direction of the wind from west to south. This is evident from Fig. 11.

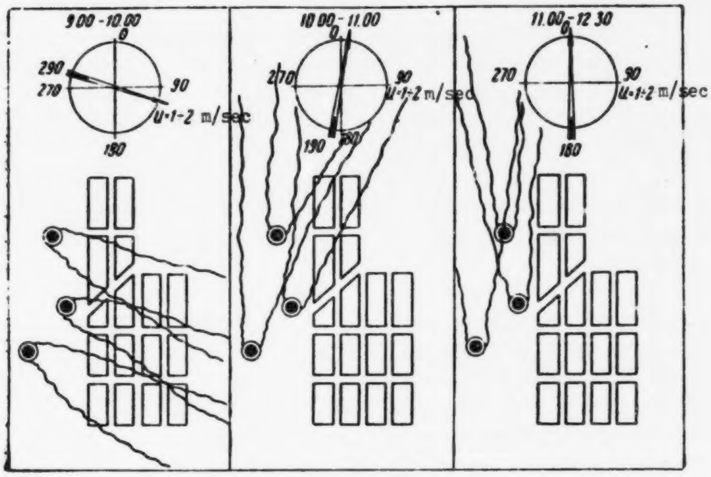

Fig. 11. Smoke pollution of the town.

As is evident from Fig. 11, from 9 to 10 A.M., almost the entire town became polluted with smoke, except its northern part, and from 10 to 11 A.M. the wind turned northward and only the northern part of the town was covered with smoke. After 11 A.M., the smoke pollution in the town practically ceased. Exposure of people in different areas of the town corresponded exactly to this turning of the wind.

A close analysis of the results of engineering and technical inspection of the plants and a study of the clinical picture of injury to people, data on the weather situation and the results of laboratory analyses of items in the external environment led to the conclusion that the cause of the large-scale poisoning of people was the pollution of the ground layer of atmospheric air by high concentrations of sulfur dioxide combined with products of its oxidation as a result of the discharge of flue gases of the boiler houses through low stacks (30-40 m). The stable, deep inversion that produced a barrier layer above the stacks of the boiler houses caused a sharp increase in sulfur dioxide concentrations in atmospheric air which turned out to be dangerous for the health of the inhabitants.

Ways of Preventing the Noxious Effects of Pollution with Sulfur Dioxide of Atmospheric Air

The data cited above, pertaining to cases of large-scale poisoning of the population, show that the struggle with atmospheric pollution by industrial discharges associated with the combustion of high sulfur fuels (particularly in industrial centers and densely populated areas) should be waged with the utmost determination.

As we have indicated above, the most significant source of pollution of urban air reservoirs in modern industrial centers are the products of incomplete combustion of fuel and sulfur oxides discharged in large quantities with flue gases from public, residential, and industrial boiler rooms and thermal electric power plants.

The most radical measure in eliminating emissions of sulfur oxides and ash is the use of natural gas as the fuel in boiler houses and thermal electric power plants.

In the construction of new towns, an effective measure consists in supplying the residential areas and industrial plants with electricity and heat from sources separated from the town by a distance such that the pollution of air with flue gases and ash is excluded. In planning residential sections and industrial plants it is necessary to consider the prevailing winds and to provide for a sufficient gap between the sources of smoke emissions and residential areas.

One of the measures limiting the discharge of sulfur into the atmosphere is the use of low-sulfur types of fuel.

In some countries of western Europe (France), special regulations have been introduced that establish a limitation on the sulfur content of fuel. Thus, the law of 20 April 1932 limited the sulfur content of fuel used for combustion in urban boiler rooms to 2%. Later, the upper limit of the sulfur content of mazut was established at no more than 0.8 - 1% (law of 12 April 1960) [67]*.

It should be noted that the elimination of sulfur from fuel prior to its use is a major problem of great economic importance. According to many experts in this field, the removal of sulfur from fuel before its use appears to be clearly advantageous. The most important results in this direction have been obtained in the case of removal of sulfur from combustible gases (natural, coke oven, water, petroleum, and other gases). The removal of sulfur from liquid fuel has been resolved only partially, and this important problem requires further research and the development of the most economical methods.

Methods of hydrogenation of petroleum permitting the production of mazut containing less than 0.5% sulfur have not yet been developed for practical applications. The removal of sulfur from solid fuel is an even more complex problem.

One of the steps taken toward reducing the pollution of atmospheric air with sulfur oxides during the combustion of high-sulfur fuel is the purification of the flue gases of electric power plants. This requirement applies primarily to high-capacity thermal electric power plants located at considerable distances from cities.

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* Editor's note: The date of publication of the reference cited is inconsistent with the date of the mentioned law.

At the present time, a number of methods have been recommended by the NIIOGAZ and Giprogazochistka Institutes for the removal of sulfur oxides from flue gases at high-capacity thermal electric power plants, but these methods have not progressed beyond the confines of experimental industrial installations. Moreover, the construction of sulfur-removing installations and the operating cost require very substantial means.

However, the construction of high-capacity State Regional Electric Power Plants has propelled the problem of purification of flue gases to a place of high priority, and it may be assumed that sulfur-removing installations will be built in the near future.

In addition to the above-enumerated methods of preventing atmospheric pollution with flue gases, in order to achieve the maximum dispersal of noxious impurities, the construction of high stacks has become widespread in the last few years. The choice of the necessary height of the smokestacks is made by calculation in accordance with the "Sanitary Standards of Planning of Industrial Enterprises" (SN-245-63), the "Temporary Method for Calculating the Atmospheric Dispersal of Discharges (Ash and Sulfur Gases) From Smokestacks of Electric Power Plants", ratified by resolution No. 83 of the State Committee on Coordination of Scientific Research of the USSR on 25 July 1963, and also by the "Recommendations for Calculating the Dispersal of Noxious Substances in the Atmosphere" [64] and [69].

In solving the problem of the necessary stack height, it should be recalled that high stacks are most effective only under favorable meteorological conditions. Because of the great dilution of gases upon their discharge through high stacks, the concentration of noxious impurities in the ground layer of atmospheric air is reduced, but the pollution zone expands considerably.

However, the construction of high stacks does not fully solve the problem of sanitary protection of atmospheric air from pollution by noxious industrial emissions.

In the case of unfavorable meteorological conditions (deep temperature inversion in combination with a low temperature and calm), which are most frequently observed in the autumn and winter, the discharge of unpurified gases will promote a considerable pollution of the atmosphere near the ground, thus posing a direct threat to the health of the population.

Of considerable assistance in the organization and adoption of appropriate preventive measures may be the meteorological service. The prediction of meteorological conditions under which the formation of dangerous concentrations of atmospheric pollutants is possible should be used to limit certain technological operations connected with the possibility of emissions of large amounts of toxic substances during that period.

The organization of a network of meteorological stations and of a service forecasting dangerous concentrations of atmospheric pollutants is necessary in areas where industry is heavily concentrated.

One of the major prophylactic steps is a regular checking of the content in the atmosphere of noxious chemicals discharged in the course of technological processes by industrial plants. The data obtained should be brought to the attention of the management of the plants for the purpose of adopting timely measures and preventing dangerous atmospheric pollutants by modifying certain features of the technological processes.

In the elimination or reduction of emissions of noxious substances into the surrounding atmosphere, a major role is played by the improvement of the technological process and by a reliable sealing of certain units, assemblies, and communications of the industrial enterprise in question.

Among ameliorative measures, of major importance is the establishment of a rigorous preventive and ongoing sanitary and technical supervision of aoo the existing and possible sources of air pollution and the implementation of all the sanitary and technical measures designed to reduce and eliminate urban air pollution.

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SOME CHARACTERISTICS OF THE METEOROLOGICAL AND AEROSYNOPTIC CONDITIONS OF SMOKE POLLUTION IN NOVOSIBIRSK

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The paper examines the results of observations of city smoke at three meteorological stations in Novosibirsk during the period 1956-1965. Analysis of the meteorological conditions on days with smoke pollution is made, and the relationships between the onset of long periods of general smoke pollution and the stratification of the atmosphere are established.

Observations of the concentration of noxious industrial discharges performed by the public health service in the cities and towns of Siberia have been few and mostly irregular. For this reason, in order to determine the dependence of the degree of pollution of atmospheric air on the meteorological conditions in Novosibirsk, an attempt was made to find indirect characteristics of pollution, using ordinary meteorological observations during climatological periods.

In Novosibirsk, there are three meteorological stations with a sufficiently long period of regular observations. Data of meteorological observations from 1950 through 1965 have established that the phenomenon of "city smoke" may serve as an indicator of the propagation of industrial discharges in individual districts of Novosibirsk.

Table 1

Average Frequency of Periods of Different Seasonal Durations in Cases for 1956-1965.

Duration of Periods / Seasons	Less Than 3 Hours	3—6 Hours	6—12 Hours	12—24 Hours	1—2 Days	2—3 Days	More Than 3 Days
Winter	1,6	1,0	2,8	5,0	5,1	2,8	3,4
Spring	2,4	4,0	4,7	2,6	3,2	1,6	0,9
Summer	1,6	1,1	0,3	0,2	—	—	—
Autumn	2,5	3,0	3,1	3,9	1,6	0,6	0,9
Average Number of Days of Smoke Per Year							
Total 71	1	2	4	9	16	15	24

Table 2

Frequency of Wind Directions and Velocities During Smoke Pollution of Different Districts of Novosibirsk as an Average for 10 Years (%)

Districts	Directions				Velocity				
	N, NE	E, SE	S, SW	W, NE	Calm	1—3	4—7	8—11	>12
Zayel'tsovskiy District	7	18	71	4	13	36	38	11	2
Dzerzhinskiy District (Northeastern) . . .	7	10	73	10	8	45	39	7	1
Kirovskiy District (Bugry, Ogurtsovo). . .	26	25	30	19	31	54	14	1	0
Average frequency of wind directions and velocities for ten years according to Ogurtsovo station.									
%	16	14	50	19	13	46	32	6	3

The ten-year series from 1956 to 1965 was found to have regular observations of "city smoke". On the basis of these data, periods were separated in which the "city smoke" was simultaneously observed at two or three stations. Results of the treatment of the data and of their analysis are shown in the tables below.

Distribution of Wind Velocities in Heights

		200						500					
Scale		0—2	3—5	6—8	9—10	>10	>15	0—2	3—5	6—8	9—10	>10	>15
Winter	%	13	53	28	5	1	0	12	49	31	6	2	0
	Total Number of Cases	124						170					
Spring	%	26	47	24	2	1	0	19	46	23	5	7	1
	Total Number of Cases	93						110					
Summer	%	17	83	0	0	0	0	33	50	0	17	0	0
	Total Number of Cases	6						6					
Autumn	%	30	38	32	0	0	0	22	43	25	8	2	0
	Total Number of Cases	37						49					
	%	20	50	26	3	1	0	16	47	27	6	4	0,3
Year	Number of Cases	53	129	68	8	2	0	55	157	89	22	12	1

It is well known that the most dangerous cases of smoke pollution are those in which high concentrations of noxious discharges act on the body for a long time.

The number of long periods (not less than 24 hours), during which the smoke pollution in Novosibirsk was observed continuously and simultaneously at two or three stations for ten years was 166, of which 42 correspond to cases where the smoke pollution was observed continuously for more than three days consecutively.

The total duration of smoke pollution amounted to 613 days for the ten-year period, i.e., of the ten years, the city lived under conditions of visible smoke pollution for almost two years.

Lasting smoke pollution was observed with particular frequency in winter and spring. In summer, the smoke pollution periods were brief and their frequency relatively low (Table 1).

Table 2 gives the frequency of the wind directions and velocities at each meteorological station during the period when "city smoke" was observed. For comparison, the last column of the table gives the mean frequency of the wind directions and velocities during the period studied. At all three stations, "city smoke" was chiefly observed at a wind velocity not above 7 m/sec. The number of smoke pollution cases in which the wind velocities at the vane level exceeded 12 m/sec was small.

Table 3

Under Smoke Pollution Conditions, Height (H)

1000						1500						2000					
0–2	3–5	6–8	9–10	>10	>15	0–2	3–5	6–8	9–10	>10	>15	0–2	3–5	6–8	9–10	>10	>15
12	36	35	12	5	0	8	39	30	15	8	1	5	31	35	13	16	0
170						170						172					
16	46	21	10	7	2	8	45	27	12	8	0	5	39	30	11	15	4
111						110						110					
33	50	0	0	17	0	50	33	C	0	17	0	0	83	0	0	17	0
6						6						6					
24	30	38	6	2	0	20	29	37	12	2	0	8	37	35	12	8	0
50						51						49					
16	39	30	10	5	0,6	10	40	29	13	8	0,6	5	35	33	12	15	1,2
53	130	101	34	19	2	35	134	98	45	25	2	18	120	110	40	49	4

The mean frequency of southern and southwestern winds in Novosibirsk for 10 years if 50%. In two districts of the city, in 72% of the total number of smoke pollution cases, there was a wind of southern and southwestern direction. In all periods of the year at levels of 200, 500, 1000, 1500 and 2000 m, a wind velocity from 3 to 8 m/sec is most frequently observed (Table 3).

In 87% of smoke pollution cases, winds not in excess of 10 m/sec were observed up to a height of 2 km, and in only 2% of the cases at one of the enumerated levels was a wind of more than 15 m/sec observed (Table 4).

Table 4

Distribution of Wind Velocities up to 2 km on Days when "City Smoke" was Observed.

Gradation	0—5	0—10	>10	>15
Number of Cases (Total 346) %	97 28	300 87	46 13	7 2

Analysis of the stratification of the ground layer on days with smoke pollution established that in 54% of the cases a ground inversion or isotherm was observed, in 23% of the cases - a raised isotherm or inversion, in 8.6% - the gradients at the surface were higher than the dry-adiabatic gradients (Table 5).

Frequency of Stratifications Based on Aerological Data

Normal Temperature Drop with Height, $\gamma < 0.8°/100$ m	Ground Inversion followed by Normal Temperature Drop	Ground Inversion followed by Isothermy and normal Temperature Drop	Ground Isothermy followed by inversion, and normal Course or Isothermy and Normal Course	Elevated Inversion
14,1	30,0	13,1	1,6	8.1

Frequency of Synoptic Situations

Cyclone	Trough	Low Gradient Field of Low Pressure	Anticyclone	Crest	Low Gradient Field of High Pressure
0,6	3,2	6,9	3,3	24,7	27,2

Analysis of synoptic processes on days with smoke pollution gave the following results: of 2419 cases, 52% were under conditions of a stable crest or low-gradient field of elevated pressure, 16% under conditions of slowly moving troughs, associated with relatively indistinct frontal partings; in 7% of the cases, the smoke pollution of the city was observed in a low-gradient field of decreased pressure, and in 14 cases (0.6%) smoke pollution was observed under conditions of a quasi-stationary cyclone (Table 6).

On the basis of the available factual material for the two-year period of observations of concentrations of dust and nitrogen oxides in the town of Kemerovo, the relationship of these ingredients with considerable precipitation (more than 3 mm per day) and the wind in the layer up to 500 m above ground level was analyzed (Table 7). These data showed that in the presence of slight winds ($V < 5$ m/sec) in the layer up to 500 m, on days with considerable precipitation, cases (10-17%) were observed where the dust concentration exceeded the maximum permissible value; in cases where the wind velocity exceeded 5 m/sec, the dust concentration was below MPC.

Observations of nitrogen oxides showed that on days with precipitation, 54% of the samples taken gave a concentration in excess of the maximum permissible value.

Table 5

in the 0-1 km layer for the Period 1956-1965 (%).

Elevated Isothermy	Inversion Followed by Abrupt Changes of the Course of Temperature	Isothermy Followed by Normal Temperature Drop	Normal Drop followed by Abrupt Changes in the Course of Temperature	Normal Temperature Drop with Height, $\gamma < 0.8°/100$ m	Total
7,7	6,9	2,3	7,6	8,6	2032 cases

Table 6

for the Period 1956-1965 (%).

Hyperbolic Point	Trough of Warm Front	Trough of Cold Front	Trough of Secondary Front or Occlusion Front	Total
2,9	8,8	6,4	16,0	2419 cases

Table 7

Characteristics of the Relationship of the Concentrations of Dust and Nitrogen Oxides to Precipitation and Wind Velocity in the Layer from 0 to 500 m for Kemerovo (1962-1963)

	Precipitation (mm)	Wind Velocity				Total Number of Cases	Cases Exceeding MPC Independently of the Wind Velocity (%)
		<5 m/sec		5—10 m/sec			
		Total Number of Cases	Cases Exceeding MPC (%)	Total Number of Cases	Cases Exceeding MPC (%)		
Surface Wind							
Dust	>3	10	10	5	—	15	6
Nitrogen Oxides .	>3	8	62	5	40	13	54
Wind in the layer up to 500 m							
Dust	>3	6	17	8	—	14	7
Nitrogen Oxides .	>3	5	40	8	62	13	54

Note. During the period studied, there were no days with precipitation on which the wind velocity exceeded 10 m/sec.

Conclusion

1. Observations of city smoke may serve as an indirect characterization of the spreading of industrial contaminants of the atmosphere in cities.

Analysis of a ten-year series of observations of "city smoke" at three stations of Novosibirsk confirmed the conclusions reached earlier from two-year observations of discharges in Kemerovo, namely: the formation of a lasting period of general smoke pollution of the atmosphere for the conditions of Siberia is most probable in a stable low-gradient field in the presence of slight winds not only near the ground but also in a thick layer of the troposphere (1.5-2.0 km) and in the presence of stable ground inversions.

2. The adopted representation of the purification of the atmosphere during periods of lasting precipitation is relative.

As was shown by our investigations, nitrogen oxides are not washed out of the air by precipitation.

3. The distribution of residential and industrial buildings in the city of Novosibirsk was planned without considering the climatic characteristics, causing the pollution of a considerable portion of the residential districts.

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SOME DATA ON THE CHEMICAL COMPOSITION OF ATMOSPHERIC AEROSOLS OF CENTRAL ASIA

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The paper presents some results of a determination of the chemical composition of aerosols under surface conditions and in the free atmosphere. The study was made for the first time in the fall of 1966 in Central Asia.

Central Asia is one of the regions of the Soviet Union with a heavily polluted atmosphere. Vast spaces occupied by sandy deserts and loesses, dryness of climate, and frequent recurrence of strong winds causing dust storms, all contribute to conditions that cause considerable amounts of various impurities to enter the atmosphere.

The study of natural aerosols is important not only from the standpoint of solution of purely meteorological problems, such as the physics of clouds and precipitation, but is also directly related to practical inquiries. The corrosive action of the atmosphere, dependent on the presence and composition of aerosols, is taken into consideration, for example, in the construction of electric power lines. The operation of compressor stations of gas pipelines, etc. depends to a large extent on the dust content of the atmosphere. Finally, the study of aerosols is related to public health problems. However, natural aerosols are being studied very inadequately. In particular, next to nothing is known about the composition of the atmospheric aerosols of Central Asia.

The results presented below were obtained from an analysis of samples collected under surface conditions and in an airplane during horizontal flights at heights of 300 and 1000 m above a considerable area of Central Asia. The aerosols were caught by means of membrane filters and filters prepared from FPP-15 fabric. In addition, a two-chamber trap with a water filter constructed by P. F. Svistov was employed. The chemical composition of soluble substances in the aerosols was determined by using a method of analysis of precipitation samples adopted at the Main Geophysical Observatory [2].

Since the underlying surface is a principal factor in the dust content of the atmosphere, it was expedient to take samples of soils most common in Central Asia. Average results from aqueous extracts on the surface layers of these soils are listed in Table 1.

According to the data of Table 1, the largest suppliers of chemically active substances to the atmosphere may become soils developed on loesses (gray desert soil) and solonchak* (saline) soils, in which the soluble part amounts to 10% or more of the total mass. Let us note that in the gray soils the higher content of soluble salts may be due to artificial factors, since these soils are used for cultivation.

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*Editor's note: Saline soils without structure.

Sandy soils, while playing a considerable part in the total dust pollution of the atmosphere, do not determine its chemical makeup, since they consist of insoluble compounds of silica to the extent of 25% and more, whereas the fraction of soluble substances amounts to less than 1%. Generally, in all the soils of Central Asia, the SiO_2 content is extremely high and ranges from 50 to 99%.

Table 1

Average Ionic Composition of Soils in % of Air-Dry Sample.

Soil	$SO_4^=$	Cl^-	NO_3^-	HCO_3^-	Na^+	K^+	Mg^{++}	Ca^{++}	NH_4^+	Soluble Part	Organic Part
Sandy	0,018	0,005	0,000	0,230	0,005	0,013	0,021	0,031	0,008	0.33	1,2
Gray desert	0,285	0.200	0,000	7,255	0,323	0,030	0,093	0,455	1.185	9,82	7,2
Solonchak	5,620	1,969	0,003	0,057	2,110	0,020	0,555	0,480	0,008	10,82	10,9

From the standpoint of the predominant soluble component, sandy soils and gray soil belong to the carbonate soil class, and solonchak soils - to the chloride-sulfate class. The latter soils contain a large amount of sodium in addition to sulfates and chlorides.

According to the existing standards of medical control of atmospheric air pollution, a single maximum permissible concentration of nontoxic dust amounts to 0.50 mg/m^3 for an average daily value of 0.15 mg/m^3. Measurements that we made on the outskirts of the city of Tashkent (Table 2), which may be assumed to characterize, more or less, the natural background pollution of the atmosphere of Central Asia, show that the total concentration of impurities in air considerably exceeds the maximum permissible concentration.

Table 2

Total Concentration (N, μg/m^3) and Ionic Composition (μg/m^3) of Aerosols of the Ground Layer of Air.

	N	$SO_4^=$	Cl^-	NO_3^-	HCO_3^-	Na^+	K^+	Ca^{++}	Mg^{++}	NH_4^+	Soluble Part		pH
											μg/m^3	%	
av.	0,80	16,3	6,8	5,7	102.1	6,0	4,0	18.3	8,3	6,5	174,0	21,1	6,15
max.	1,31	44,2	18.2	18.4	164.4	10,9	7,4	31,4	14,3	30,0	—	27,6	6,35
min.	0,46	0,0	0,0	0,0	25,4	3,1	2,5	3,6	3,9	9,0	—	11,2	5,96

Of 30 series of measurements made in September-October 1966 at different times of the day, the average mass concentration of aerosols in the surface layer of air was 0.80 mg/m^3 between variation limits of 0.46 to 1.34 mg/m^3. This low variability indicates the constancy of high aerosol concentrations in the atmosphere.

As follows from the data of Table 2, the aerosols of the ground layer of air contain a relatively large amount (21%) of soluble substances. An increase in the fraction of soluble matter in atmospheric dust as compared with the soil obviously results from the ascent into the atmosphere of lighter particles having a higher percentage of the soluble fraction than the heavy particles that remain on the surface of the soil and consist mainly of silica. The increase of the soluble part in the particles with an increase of their dispersion is indicated, for example, by analyses of suspended alluviums of rivers [3]. Very fine particles resulting from industrial production and suspended in air may also have a certain effect.

In the ionic composition, the predominant component is unquestionably the bicarbonate ion HCO_3^-, which accounts for 78% of the anions and 12.8% of the total concentration. Despite the wide limits of variation of the concentration, HCO_3^- is the only anion observed in all the samples.

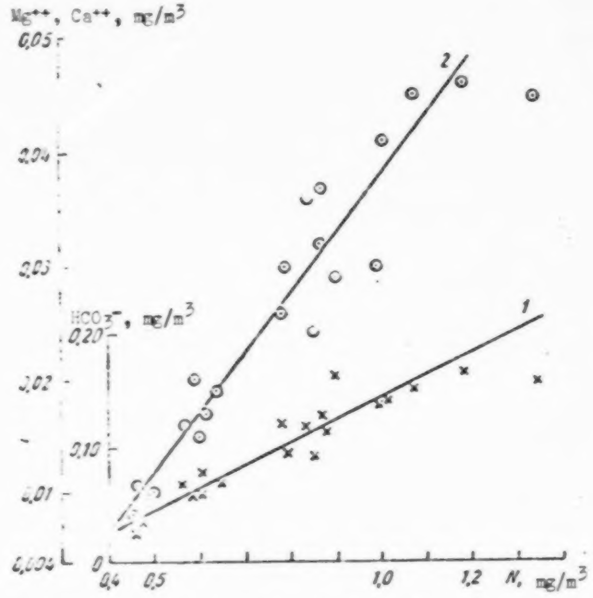

Fig. 1. Relationship between the total concentration of aerosols in the ground layer of air, the ions HCO_3^- (1), and $Mg^{++} + Ca^{++}$ (2).

In second place among the anions is the sulfata ion SO_4^{--}, whose average content is 16.3 μg/m^3, which amounts to 2% of the total aerosol concentration. The content of chlorine and nitrates is considerably lower, their average of aerosols at the heights of 300 and 1000 m. According to the data cited, it is equal to 0.66 and 0.49 mg/m^3 respectively. Actually, the mass concentration of aerosols at these heights will be slightly lower, since the fraction of soluble substances in the fine particles increases.

As can be seen from Table 3, the decrease of coarse particles with the height occurs much more rapidly than in the case of fine particles. At the 1000 m height as compared with the 300 m level, the change in the concentration of coarse particles amounts to 30%, and that of fine particles, to only 9%. At the same time, the contribution of fine particles to the total aerosol mass increases slightly, from approximately 20 to 24%.

At the 300 m height, as at ground level, HCO_3^- ions predominate, but the sulfate ions make a contribution commensurate with that of HCO_3^- to the soluble portion of aerosols. At the 1000 m height, the content of SO_4^{--} is already higher than that of bicarbonate ions. The ratio SO_4^{--}/Cl^- at the heights and near the ground remains approximately the same and equal to two.

It is usually assumed that chlorides in the atmosphere are of marine origin, and sulfate of continental origin. Furthermore, an inverse proportion is observed between their contents. Fig. 2 showed the relationship between the sulfate and chloride concentrations obtained on the basis of our measurements in the free atmosphere. It is noteworthy that here, with the exception of two samples taken directly above the Caspian and Aral Seas, a linear dependence exists between the chlorides and sulfates in aerosols, indicating a single source of their origin.

As already noted, it is obvious that the main suppliers of these salts to the atmosphere are solonchak soils or soils having different degrees of salinization and salinity and occurring throughout Central Asia.

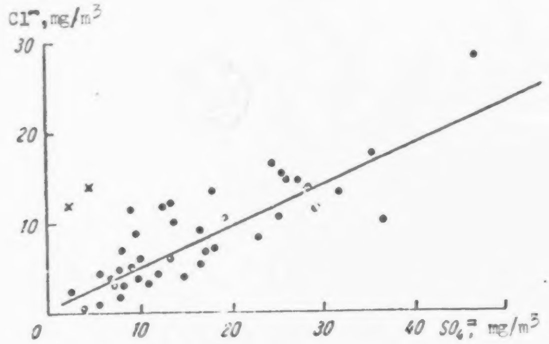

Fig. 2. Relationship between concentrations of chloride and sulfate ions in aerosols of the free atmosphere.

concentration being 6.8 and 5.7 $\mu g/m^3$, respectively.

Among the cations, the predominant one is Ca^{++}, with a concentration of 18.3 $\mu g/m^3$, this being more than twice the content of Mg^{++}, which is in second place. The concentration of cations is less variable than that of anions, and with the exception of NH_4^+, all of them were observed in all the samples.

The constant presence of certain ions in the samples makes it possible to follow their relationship to the total aerosol concentration. The presence of a direct relationship between the total aerosol concentration and the HCO_3^-, Ca^{++} and Mg^{++} ions, illustrated in Fig. 1, indicates that in addition to their substantial contribution to the total concentration, these ions should be present in certain definite ratios. As was shown by analysis, these ratios are the same as in $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. Apparently, the carbonate particles of calcium and magnesium, present in high concentrations in aqueous solution in the ground layer of air, convert into completely soluble bicarbonate compounds. This situation may be of essential importance for the chemistry of precipitation.

Average data on the chemical composition of aerosols in the free atmosphere are shown in Table 3. The double chamber trap made it possible to separate the trapped aerosol particles into two fractions (coarse and fine) with a$\sim$0.5 μ limit.

Table 3

Average Ionic Composition of Aerosols of the Free Atmosphere ($\mu g/m^3$).

Height, m	Particles	$SO_4^=$	Cl^-	NO_3^-	HCO_3^-	Na^+	K^+	Mg^{++}	Ca^{++}	NH_4^+	Total ions	pH
300	coarse	25,6	12,6	0,1	43,6	2,0	1,4	5,6	14,9	5,4	111,2	5,70
	fine	8,0	6,1	0,0	0,9	1,5	1,0	3,4	2,2	3.7	26,8	5,27
	total	33,6	18,7	0,1	44.5	3,5	2.4	9,0	17,1	9,1	138,0	—
1000	coarse	20,6	10,1	0,0	24,5	1,6	1,3	4,8	12,0	3,3	78,2	5,56
	fine	9,1	5,4	0,1	0,4	1,3	1,0	3,0	1,3	2,9	24,5	5,17
	total	29,7	15,5	0,1	24,9	2,9	2,3	7,8	13,3	6,2	102,7	—

From the data of Table 3 it follows that the content of soluble substances in aerosols and hence the total pollution of the atmospheric layer studied is rather high. Whereas near the ground the total ions in aerosols amount to 174 $\mu g/m^3$ or approximately 21% of the total concentration, at heights of 300 and 1000 m they amount to 138 and 103 $\mu g/m^3$ respectively. This slow decrease may be explained by the fact that all the measurements in the free atmosphere were made during the daytime, when the vertical displacements of air in Central Asia are highly developed.

Assuming the percentage ratio between the soluble and insoluble parts to be constant with the height, we shall evaluate the total concentration

The content of nitrates in the atmosphere of Central Asia is slight. We observed practically detectable values (1.4 and 0.6 $\mu g/m^3$) in only two samples out of 42. Apparently, the NO_3^- in aerosols of the ground layer of air is of industrial origin, since in soils (Table 1) and also in the waters of the Caspian and Aral Seas [1], nitrogen oxides are either present in negligible amounts or totally absent.

Among cations in aerosols of the free atmosphere, Ca^{++} also predominates. On the average, in the atmospheric aerosols of Central Asia in the layer studied (up to 1000 m), the cations may be arranged as follows:

$$Ca^{++} > Mg^{++} > NH_4^+ > Na^+ > K^+.$$

The changes taking place in the cationic composition of coarse and fine aerosols are very interesting (Table 4).

Table 4

Ratio of Cations in Coarse and Fine Aerosols.

Height, m	$\frac{Ca^{++}}{Mg^{++}}$		$\frac{Ca^{++}}{Na^+}$		$\frac{Ca^{++}}{K^+}$	
	Coarse Particles	Fine Particles	Coarse Particles	Fine Particles	Coarse Particles	Fine Particles
200	2,66	0,65	7,45	1,46	10,64	2,20
1000	2,50	0,43	7,50	1,00	9,23	1,30

The data of Table 4 suggest that as the height and dispersion of the particles increase, so does their relative content of Mg^{++}, Na^+ and K^+, whereas on the contrary, the Ca^{++} content decreases. In addition, the content of Mg^{++} even surpasses that of Ca^{++}, and makes the most substantial contribution to the cationic composition of fine aerosols, no account being taken of NH_4^+, whose nature is different.

It is to be noted that the behavior of HCO_3^- displays certain characteristics analogous to those of Ca^{++}. This indicates that the carbonate particles of calcium are primarily coarse and that their concentration decreases relatively rapidly with the height.

The character of the variations in the ionic composition of aerosols may be followed most conveniently by using schemes obtained on the basis of stoichiometric calculations, using the accuracy of the chemical analysis of the samples. These schemes show that the most probable simple molecular compounds in the solutions of aerosols in the ground layer of air are $Ca(HCO_3)_2$, $Mg(HCO_3)_2$, $MgCl_2$, NaCl, $(NH_4)_2SO_4$, and KNO_3. In the free atmosphere, the coarse particles consist of the compounds $Ca(HCO_3)_2$, $CaSO_4$, $MgSO_4$, $(NH_4)_2SO_4$, $MgCl_2$ and NaCl, and the fine particles, of the compounds

$NaCl$, $MgCl_2$, $CaSO_4$, and $(NH_4)_2SO_4$.

It follows that the character of the compounds present in aerosols undergoes considerable changes with the height: at the height, carbonates of magnesium and nitrates are absent, whereas calcium and magnesium sulfates appear. Fine particles are characterized by the absence of bicarbonate compounds. Consequently, whereas coarse particles chiefly have an alkaline reaction, fine particles have an acid character. This is also indicated by a decrease of the pH in fine aerosols.

In Central Asia, there are frequent dust storms in which enormous amounts of dust are raised from the surface of the ground into the atmosphere. It is therefore of interest to consider the results of a chemical analysis of aerosols collected during a flight at a height of 300 m during a dust storm in the region of the town of Nukus on 9 October 1966 (Table 5). The last line of this Table shows by what factor the impurity concentration (C) was increased at the height of 300 m during the dust storm as compared with the average data ($\bar{C}$) shown in Table 3.

Table 5 shows that during the dust storm, the aerosol concentration in the atmosphere at the height of 300 m increased by a factor of almost 15 as compared with the average data, owing primarily to calcium and magnesium carbonates. Generally speaking, this may be indicative of the given location without being characteristic, for example, of a region with saline soils.

Table 5

Chemical Composition of Aerosols During Dust Storm ($\mu g/m^3$).

	$SO_4^=$	Cl^-	HCO_3^-	Na^+	K^+	Mg^{++}	Ca^{++}	Total ions
C	85,1	25,5	1487,9	14,2	8,5	126,2	266,7	2014,1
$C/\bar{C}$	2,5	1,4	33,4	4,1	3,5	14,0	15,6	14.6

An evaluation of the total content of aerosols from their soluble portion has shown that during this dust storm at the 300 m height, there were approximately 10 mg of impurities per m^3 of air. This value is in good agreement with the concentration measured directly, equal to 10.92 mg/m^3.

In summary, the following comment may be made. Under the influence of specific physical-geographic and climatic conditions, the content of impurities in the atmosphere of Central Asia surpasses the maximum permissible concentrations established by public health standards, and does so tens of times more during dust storms. During the warm period of the year, dust pollution involves a considerable thickness of the atmosphere. Hence, Central Asia may be regarded as a kind of focus in which the dust is generated and then transported to other regions by air currents.

Since they contain a considerable fraction of soluble substances (over 20%), aerosols on the one hand may influence the chemistry of precipitation, and on the other hand generally increase the aggressive properties of the atmosphere, particularly its corrosiveness, because of the presence of chlorides, whose constant source are solonchak soils and the Caspian and Aral Seas.

This high percentage of soluble substances makes it possible to regard Central Asian aerosols as active condensation nuclei, although primarily potential ones, since, because of the insufficiency of saturation, the condensation level in Central Asia is high (in the summertime, usually above 2 km).

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CHEMICAL COMPOSITION OF CLOUD WATER IN URBAN INDUSTRIAL DISTRICTS UNDER VARIOUS WEATHER CONDITIONS

O. P. Petrenchuk and V. M. Drozdova

From Trudy, Glavnaya Geofiz. Observat. im. A. I. Voeykova, No. 238, p. 201-209, (1969).

Various pollutants reaching the atmosphere as a result of human activity spread to great distances. Investigations [3, 4, 5] show that the influence of a major city can be detected at distances up to 100-150 km in the direction of the wind. Pollutants also reach great heights in the vertical direction, affecting the physical and chemical processes in the atmosphere.

A considerable amount of impurities can concentrate in clouds, particularly when the stratification of the atmosphere is stable, and be carried together from some areas to others.

An important part in the purification of the atmosphere is played by precipitation. The latter traps impurities during both its fall and formation. Thus, by using data on the chemical composition of precipitation one can reliably estimate the degree of pollution of the layers of the atmosphere through which it passes.

In order to study the formation of the chemical composition of precipitation, the A. I. Voyeykov Main Geophysical Observatory has for many years conducted systematic research on the composition of atmospheric waters, including precipitation and cloud water [1, 2, 8]. Preliminary results have shown that the chemical composition of cloud water varies with the area of sampling. The mineralization of water taken from subinversion clouds provides an indirect characterization of the air pollution in the region of sampling [2, 8]. However, a closer analysis indicates that the composition of cloud water substantially depends on the weather conditions and the nature of the clouds.

The article considers the chemical composition of water taken from clouds in the eastern regions of the European Territory of the USSR, mainly in the vicinity of Kazan' and neighboring towns. Work on the sampling of cloud water was organized here in 1965 and is still being carried out. Analysis of extensive material (about 200 samples) collected in the course of a period of over 3 years (1965-1968) from various types of clouds under various synoptic conditions makes it possible to establish a number of characteristics.

Kazan' is a major industrial city. The atmosphere of not only the city itself but also its surroundings is heavily polluted. This has been reflected in the chemical composition of the water of subinversion clouds formed under anticyclonic conditions in this region.

Fig. 1 shows a series of typical examples at the temperature stratification of the atmosphere in Kazan' and other towns in the east of the European Territory or the USSR, when the mineralization of cloud water reached extremely high values, of the order of 100-120 mg/l. The cases cited pertain to stratified clouds of low vertical thickness (200-400 m) existing under anticyclonic conditions. The average chemical composition of cloud water collected from stratified subinversion clouds during the three-year period is shown in Table 1. This table also lists data on the chemical composition of water from clouds giving no precipitation and not associated with temperature inversions, and for comparison, the average chemical composition (for 4 years) of precipitation in the eastern regions of the European Territory of the USSR.

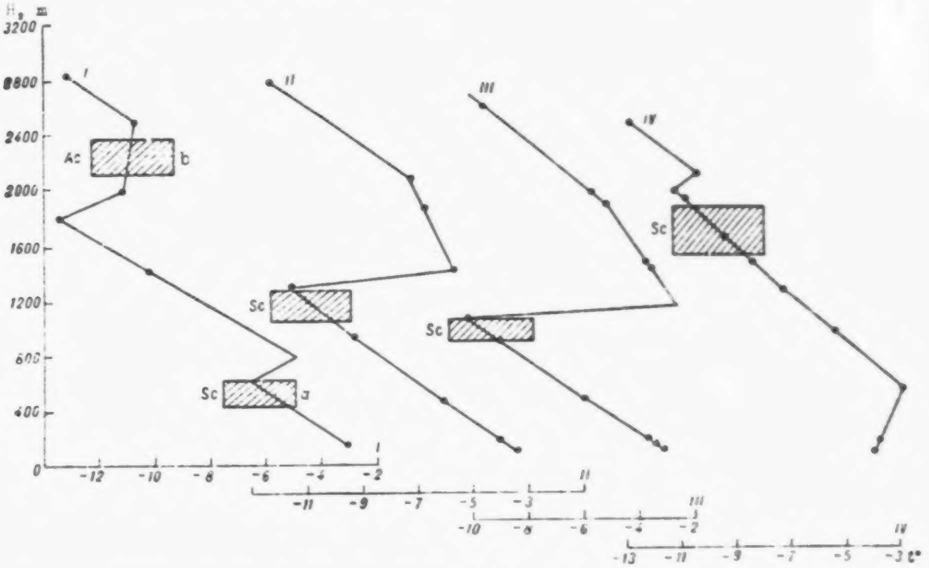

Fig. 1. Results of temperature sounding of the atmosphere during the collection of cloud water samples in 1967.

I - 18 February, town of Mamadysh: a) Σ_{ion} = 79.6 mg/l, κ = 183 x 10^{-6} ohm^{-1} cm^{-1}, b) κ = 86 x 10^{-6} ohm^{-1}cm^{-1}; II - 16 March, Kazan', Σ_{ion} = 88.7 mg/l, κ = 303 x 10^{-6} ohm^{-1}cm^{-1}; III - 15 March, Kazan', Σ_{ion} = 93.4 mg/l, κ = 276 x 10^{-6} ohm^{-1}cm^{-1}; IV - 4 March, Kazan', Σ_{ion} = 120.4 mg/l, κ = 398 x 10^{-6} oHm^{-1}cm^{-1}.

As is evident from the table, the chemical composition of cloud water is greatly influenced by the meteorological conditions. Water from clouds forming in the absence of inversions is much less mineralized than in subinversions clouds. However, it also retains a proportion of the main ions characteristic of continental conditions. The concentration of $SO_4^=$ ions and the ratio $SO_4^=/Cl^-$ are fairly high, attesting to the influence of industrial sources on the chemical composition of clouds forming also in the absence of inversions.

The mineralization of water from nonprecipitating clouds is close in magnitude to the mineralization of precipitation in the region of the Volga River. However, since the formation of the chemical composition of the precipitation occurs not only in the clouds, but also in the subcloud layer during the fail of precipitation, it is evident that data on the chemical composition of these clouds cannot be used to evaluate the contribution of the clouds.

Table 1

Average Chemical Composition of Cloud Water and Precipitation in Eastern Regions of the European Territory of the USSR.

Type of Sample	Concentrations, mg/1									pH	$\kappa \times 10^6$ ohm^{-1} cm^{-1}	Σion	Number of Samples
	$SO_4^=$	Cl^-	NO_3^-	HCO_3^-	NH_4^+	Na^+	K^+	Mg^{++}	Ca^{++}				
Sub-inversion cloud	45,3	3,4	1,3	2,4	6,4	3,3	1,2	2,7	7,4	4,71	206	73,4	41
Clouds producing no precipitation and not associated with inversions	12,3	1,8	0,6	2,4	1,7	1,1	0,5	1,2	2,3	5,68	46	23,9	59
Precipitation	9,2	2,1	1,3	5 6	0,9	1,5	0,7	1,5	2,0	6,00	45	24,8	

A considerable amount of impurities accumulate in the subinversion clouds.

In clouds forming during periods of prolonged existence of an anticyclonic situation, the concentration of impurities is still higher. Table 2 gives the results of an analysis of cloud samples collected from the end of February until April 1967 around Kazan' and in other cities located at distances of about 100-250 km from Kazan'. During that period, the eastern part of the European Territory of the USSR was under a low-gradient high-pressure area between two vast stationary centers: the Azores' and Siberian anticyclones. Everywhere at the points of collection, a high mineralization of cloud water was observed which exceeded 120 mg/1 (samples No. 1, 5, 6) and sometimes 300 mg/1 (sample No. 4).

In almost all the samples, a high concentration of hydrogen ions was observed, which corresponds to rather low pH values (from 3.1 to 4.8, with the exception of samples No. 16 and 17). In all the samples, the predominant anion is $SO_4^=$. Its content is 74-97% of the total anion composition. The chlorine content ranges from 2.4 to 24%. Of the cations, the most abundant is HN_4^+ (from 18 to 46%) in the majority of samples, and the content of the remaining cations is extremely varied.

As follows from Table 2, the pollutants concentrate in the clouds not only in the immediate vicinity of Kazan'. A high concentration of pollutants is also observed in cloud water collected in the vicinity of towns at distances of 100-200 km from Kazan', such as Chistopol', Mamadysh, Leninogorsk, etc.; the height to which the impurities spread reaches over 3 km in some cases (sample No. 17). It is obvious, therefore, that under conditions of a distinct anticyclonic situation and a weak turbulent exchange, a high pollution level is produced over a considerable part of the east of the European Territory of the USSR and remains there for a long time.

An entirely different picture is observed in the case of frontal clouds. As in the case of a study of the chemical composition of cloud water in towns of Western Siberia [2], the water samples from the frontal precipitating clouds in the region of Kazan' contain a small amount of impurities (Table 3). Its total mineralization amounts to only about 8 mg/l, and for regions of western Siberia, 6 mg/l.

Table 3 gives analyses of samples taken from stratified rain clouds and convective clouds of types Ac, As, Ns, Cb. It is obvious that the mineralization of the samples depends little on the type of the clouds or their vertical thickness. No distinct dependence on the height of the collection was observed either.

Chemical Composition of Heavily Polluted Samples

Sample Number	Region	Date	Cloud Type	Height of Sample Collection, m	Concentration		
					$SO_4^{=}$	Cl^-	NO_3^-
1	Mamadysh	8 II	Sc	800	106,00	3,12	0,76
2	Vicinity of Mamadysh .	9	Sc	990	53,00	5,67	0,78
3	Mamadysh	18	Sc	530	46,00	8,03	0,73
4	Vicinity of Chistopol' . .	28	Sc	680	256,00	5,57	0,84
5	Vicinity of Kazan' . . .	4 III	Sc	1770	79,00	9,90	0,89
6		6	Sc	1175	99,00	5,03	0.82
7	Vicinity of Leninogorsk	6	Sc	1040	42.00	2,37	0,78
8	Vicinity of Kazan' . . .	15	Sc	1000	68,00	1,55	0,73
9	Vicinity of Chistopol' .	15	Sc	850	55,80	1,42	0,80
10	Vicinity of Kazan' . .	16	Sc	960	58,00	2,90	0,81
11		16	Sc	1230	64,00	1,18	0,78
12	Shumerli	16	Sc	1300	27,00	1,62	0,63
13		16	Sc	1170	27,20	4,03	0,65
14	Kanash	17	Sc	1375	26,00	2,78	0,62
15	Mamadysh	21	Sc	1090	72,00	6,19	0,80
16	Shumerli	6 IV	Ac	2800	40,60	2,91	0,11
17	Vicinity of Shumerli . .	6	Ac	3180	41,70	2,80	0,51

Water taken from clouds formed in a cold air mass moving from the north in the forward part of the anticyclone (Table 4) was found to be similar in chemical composition and mineralization. As a rule, the vertical thickness of these clouds did not exceed 1500 m. Independently of the type of clouds, the samples of cloud water contained a small amount of impurities in this case as well. There was also observed a certain tendency on the part of the water of mineralization to decrease with height, this being due to a change in the microphysical characteristics of the clouds. Thus, in several cases (6 May, 11 August, 12 September - samples No. 1-4, 7-8, 9-10 respectively) a decrease in the mineralization of water with height was associated with a corresponding increase of the water content.

Data on the chemical composition of water from frontal precipitating clouds are of great interest. They are important in the study of the process of precipitation formation and also in evaluating the formation of the chemical composition of precipitation and its washing action. However, such data are very scarce at the present time. We can only mention the works of Oddie [7] and Komabayasi [6], correlating the results of single overflights of small regions. According to Ref. [6], where the change of the electrical conductivity in rain water was studied at various heights in convective clouds over the Hawaiian Islands, the mineralization of cloud water substantially decreased with height. The electrical conductivity changed from an average of (80-100) x 10^{-6} $ohm^{-1}cm^{-1}$ to (10-20) x 10^{-6} $ohm^{-1}cm^{-1}$.

Table 2

Collected Under Anticyclonic Conditions (1967)

mg/1							K x 10^6 $ohm^{-1}cm^{-1}$	Σ ion
HCO_3^-	NH_4^+	Na^+	K^+	Mg^{++}	Ca^{++}	pH		
0,00	15,20	2,80	2,67	3,48	1,95	3,09	671	135,98
0.00	3,75	4,35	1,75	3,26	2.60	3,30	338	75,16
0,00	10,30	6,60	1,15	1,78	5,00	4,75	183	79,59
0,00	19,00	4,22	8,28	10,80	55,00	3,30	821	359,71
0.00	11,60	8,60	1,40	2,71	6.30	3,34	398	120,40
0,00	8,20	3,37	1.60	5,06	9,90	3,52	281	123,98
0,00	7,85	1,85	0,92	2,03	4,30	4,06	172	62,10
0,00	10,60	1,60	0,63	4,43	5,87	3,60	276	93,41
0,00	9,30	0,98	0,55	3,90	1,03	3,75	254	73,78
0,00	9.30	1,88	0,77	3,30	7.60	3,79	307	81,56
0,00	10,80	1,85	0,85	2,28	7,00	3,73	303	88,74
0,00	5,60	1,20	0,70	1,13	3,70	4,85	77	41,58
0,60	5,65	1,10	0,65	0,52	4,30	4,35	107	44,10
0,00	4,90	1,45	0,80	1,14	4,10	4,36	98	41,79
0,00	5,20	4,20	1,25	4,86	8,63	3,38	380	103,13
11,77	1,27	0,00	1,61	2,09	11,50	6,04	144	78,16
10,90	1,28	9,80	2,20	1,20	10,50	6,10	149	80,92

Chemical Composition of Cloud Water

Sample No.	Region	Date	Cloud Type	Height of Collection, m	Concentration,		
					$SO_4^{=}$	Cl^-	NO_3^-
1	Vicinity of Kuybyshev . .	28 VI 1965	Cb	2750	3,80	0,58	0,22
2	50 km from Kuybyshev		Cb	3400	3,90	0,91	0,00
3	Vicinity of Menzelinsk . .	21 VII 1965	Ac	1850	1,70	0,46	0,20
4		22 VII 1965	Cb	2740	1,75	0,50	0,67
5			Cb	3220	1,60	0,39	0,07
6			Cb	3470	2,15	1,00	0,0
7	Chistopol'	23 VII 1965	Cb	3250	[illegible],60	1,20	0,00
8			Cb	3500	5,70	0,80	0,00
9			Cb	2880	5,30	1,20	0,23
10	Vicinity of Alatyr'	15 II 1966	Ns	1500	4,90	1,68	0,16
11	Vicinity of Ul'yanovsk . . .	16 II 1966	Ns	2190	4,90	0,34	0,00
12	Cheboksary	15 III 1966	Ns	2700	3,90	0,67	0,04
13			Ns	3160	3,90	0,87	0,04
14	Mamadysh	15 IX 1967	Ac	3020	1,50	1,28	0,00
15	50 km south of Izhevsk . . .	15 IX 1967	Ac	2650	2,70	0,92	0,00
16	80 km south of Izhevsk . . .		Ac	2990	2,50	1,29	0,00
17	Shumerli	13 IX 1967	As	4130	3,10	0,61	0,05
18			As	3600	3,10	0,57	0,00
19	Mamadysh	24 IX 1967	As	2590	2,80	0,43	0,00
20	70 km east of Kazan' .	16 IV 1968	Cb	2900	2,00	0,71	0,00
21			Cb	1600	2,30	1,46	0,23
	Average				3.10	0,85	0,09

Chemical Composition of Water From Clouds

Sample No.	Region	Date	Cloud Type	Height of Collection, m	Concentration,		
					$SO_4^{=}$	Cl^-	NO_3^-
1	Vicinity of Kazan'	6 V 1965	Cu	850	6,00	0,69	0,37
2			Cu	935	3,60	1,41	0,23
3	200 km west of Kazan' . .		Cu	1180	3,30	1,07	0,16
4	Vicinity of Gor'kiy		Cu	1360	2,75	0,69	0,12
5			As	2130	5,90	0,63	0,3
6	Vicinity of Kazan'	20 V 1965	Cb	4260	2,80	0,82	0,27
7		11 VIII 1965	As	3760	4,30	0,79	0,00
8			Ac	4350	2,90	0,79	0,00
9	Chistopol'	12 IX 1967	Ac	3050	8,00	0,92	0,00
10			Ac	3240	2,70	0,57	0,10
11	Mamadysh	14 IX 1967	Ac	4140	2,75	1,21	0,00
	Average				4,03	0,87	0,14

Table 3

From Frontal Clouds.

mg/l						pH	$K \times 10^6$ $ohm^{-1}cm^{-1}$	Σ_{ion}
HCO_3^-	NH_4^+	Na^+	K^+	Mg^{++}	Ca^{++}			
2,26	0.18	0.32	0.35	0,98	1.12	5,74	16	9,81
2,81	0,26	0.41	0,43	0,56	1,65	5,92	18	10,93
1,39	0,48	0,10	0,10	0,59	0,58	5,45	14	5,60
0,61	0,48	0,29	0,24	0,23	0,90	5,85	10	5.67
2.46	0,30	0,18	0,15	0.37	0.90	6,25	9	6,42
1,58	0,20	0,21	0,21	0,26	0,71	5,81	11	6,32
1,34	0,00	0,35	0,23	0,41	0,54	5,60	11	5,67
0,00	0,88	0,20	0,20	0,28	1,00	4,85	20	9,06
0,27	0,88	0.47	0.47	0,28	0,81	5,50	19	9.91
0,61	0,89	0,36	0,15	0,61	1,29	5,32	24	10,65
0,00	0.47	0,23	0,22	0,23	0.47	4,84	18	6,86
—	0,68	0,36	0,27	0,25	0,20	—	15	6,37
0,60	0,44	0,41	0,20	0,29	0,90	5,30	18	7,65
2,74	0,70	0,50	0,20	0,27	0,40	6,00	12	7,59
0,00	0,36	0,30	0,11	0,21	0,50	5,00	13	5,10
2,62	0,53	0,62	0,42	0,30	0,55	5,90	16	8,83
1,71	0,98	0,19	0,11	0,21	0,43	6,15	12	7,42
4,58	1,50	0,29	0,10	0,39	0,70	6,30	18	11,23
1,46	0,56	0,19	0,09	0,32	0,52	6,05	10	6,43
1,53	0,25	0,12	0,04	0,48	0,78	5,90	9	5,91
2,01	0,39	0,50	0,30	0,44	0,60	5,95	14	8,23
1,52	0,54	0,31	0,22	0,38	0,74	5,68	15	7,75

Table 4

Formed Upon Intrusion of Arctic Air Masses

mg/l						pH	$K \times 10^6$ $ohm^{-1}cm^{-1}$	Σ_{ion}	Water Content, g/m^3
HCO_3^-	NH_4^+	Na^+	K^+	Mg^{++}	Ca^{++}				
0,00	0,87	0,17	0,30	1,00	1,08	5,44	23	10,48	0,18
0,06	0,26	0,22	0,21	0,89	0,74	5,30	17	7,05	0,21
0,00	0,35	0,20	0,22	0,52	0,67	5,38	12	6,49	0,27
0,00	0,20	0,12	0,13	0,47	0,48	5,20	10	4,96	0,27
0,00	0,88	0,12	0,13	0,68	0,40	4,96	29	9,08	0,18
0,00	0,39	0,19	0,20	0,47	0,72	5,55	15	5,86	0,28
0,00	0,50	0,08	0,22	0,30	0,74	5,00	18	6,93	0,15
0,00	0,18	0,22	0,19	0,21	0,57	4,97	15	5,06	0,28
0,00	1,20	0,40	0,21	0,49	0,80	5,10	26	12,02	0,35
0,37	0,75	0,20	0,10	0,16	0,33	5,35	12	5,28	0,38
2,32	0,91	0,41	0,38	0,21	0,51	5,98	14	8,70	0,24
0.25	0,59	0,21	0,21	0,49	0,64	5,29	17	7,43	

This decrease was explained on the basis of the salt hypothesis, according to which each raindrop is formed from a corresponding giant salt nucleus, and the number of coarse salt particles per unit volume of cloud air decreases with the height faster than the water content of the cloud. Obviously, this hypothesis is valid for the thermal convective clouds in the region of Hawaii, whose drops are formed by the condensation of water vapor on giant condensation nuclei of marine salts, and for which a considerable inhomogeneity of microphysical characteristics is typical.

As far as frontal clouds forming at middle latitudes under continental conditions are concerned, our data do not show any clear-cut dependence of the mineralization on the height. This may be because there is little probability of the presence of coarse salt particles in the free atmosphere under continental conditions. Furthermore, low velocities of ascending currents are usually observed in stratified and stratified-cumulus rain clouds, and this promotes more homogeneous microstructural characteristics and the precipitation of finer droplets than in convective clouds. In addition, in the existing method of sampling of cloud water, the collection of each sample consumes a certain time interval (10-20 minutes) during which water from various parts of the cloud may reach the sample. As a result, the change of mineralization with height may also be masked in convective clouds (sample Nos. 1, 2 and 7, 8, 9, Table 3), whose microphysical characteristics are marked by inhomogeneity.

Table 5

Chemical Composition of Water of Frontal Precipitating Clouds.

Region	Concentration, mg/liter									pH	κ x 10^6 $ohm^{-1}cm^{-1}$	Σ ion	Number of Samples
	SO_4	Cl	NO_3	HCO_3	NH_4	Na	K	Mg	Ca				
The North of European USSR	2,5	0,8	0,2	0,6	0,5	0,2	0,2	0,3	0,8	5,4	13,6	6,2	15
The Northwest of European USSR	3,1	1,2	0,3	0,2	0,6	0,5	0,3	0,2	0,2	5,0	18,5	6,6	20
The Southwest of European USSR	2,4	1,0	0,2	0,9	0,8	0,3	0,2	0,2	0,3	5,5	12,5	6,3	25
The Southeast of European USSR	3,1	0,8	0,1	1,5	0,5	0,3	0,2	0,4	0,7	5,7	14.6	7.6	21
Regions of Western Siberia	2,8	0,6	0,3	0,6	0,4	0,3	0,2	0,3	0,3	5,1	13,6	5,8	44
Average . . .	2,8	0,8	0,2	0,7	0,7	0,3	0,2	0,3	0,4	5,3	14,3	6,2	125

Considering the decisive role played by the chemical composition of the water of frontal clouds in the formation of the composition of atmospheric precipitation, we have compared the chemical composition of the water of frontal clouds for different regions of the Soviet Union. We used data which we obtained from scientific flights in the north of the European Territory of the USSR (vicinity of Arkhangel'sk, Nar'yan-Mar, etc.), northwest of the European Territory (vicinity of Leningrad, Cherepovets, Pskov, etc.), southwest of the European Territory (vicinity of Kiev, Minsk, Dnepropetrovsk), and some other regions of western Siberia (vicinity of Krasnoyarsk, Turukhansk, Yeniseysk, etc.) [2]. The results are listed in Table 5.

An examination of the data of Table 5 shows the very low mineralization of frontal clouds. It is almost identical in different regions and amounts to an average of 6.2 mg/l. This value changes relatively little with time as precipitation takes place (Fig. 2), and should obviously be used in evaluating the contribution of clouds to the formation of the composition of precipitation.

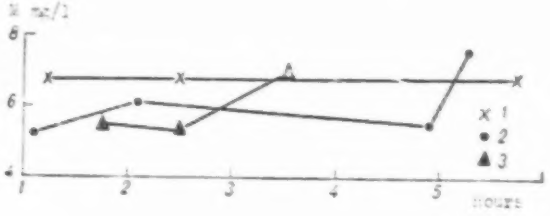

Fig. 2. Change in the mineralization of water from frontal clouds during precipitation.

1 - Simferopol', 19 April 1965; 2 - Kiev, 22 November 1967; 3 - Krasnoyarsk, 1 November 1965.

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CHEMICAL COMPOSITION OF ATMOSPHERIC PRECIPITATION OF THE CITY OF PERM' AND CONTROL OF ATMOSPHERIC POLLUTION

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From Akad. Nauk SSSR. Ural. Filial. Komis. po Okhrane Prirody. Okhrana prirody na Urale. II. (Perm', 1961), p. 45-50.

It is usually assumed that atmospheric precipitation, i.e., rain and snow, consist of water that is nearly chemically pure. Actually, this is not the case. Only in regions distant from seas and populated areas is the mineralization of atmospheric precipitation slight. For example, in the region of Bol'shiye Koty settlement on the western shore of Lake Baykal, it amounts to only 7.0-9.5 mg/l (K. K. Votintsev, 1954). In the remaining regions of the globe, the mineralization is usually higher; for the USSR, it amounts to an average of 46.42 mg/l. The highest mineralization within the boundaries of the Soviet Union has been observed at the Aral Sea station (Kazakh SSR), where it was found to be 561.5 mg/l, the average of two samples (Ye. S. Burkser et al., 1952; N. Ye. Fedorova, 1954).

The mineralization sources of atmospheric cloud water and of the atmospheric precipitation issuing from them are quite varied. First of all, the atmosphere always contains very fine solid mineral substances in the form of salts of marine and partly volcanic origin. In addition, upon hydration and dissociation, the carbonic acid dissolved in atmospheric water yields hydrogen ions and the bicarbonate ion, while atmospheric electric discharges result in the formation of oxides of atmospheric nitrogen. However, all these and other sources cause a mineralization of cloud water of only 3-7 mg/l. Marine salts (in the absence of volcanic eruptions) are usually of prime importance in this case.

The chemical composition of atmospheric precipitation differs from that of cloud water. In addition to the latter, it is determined by the amount of dry soluble substances present in air, the amount and nature of the precipitation, and also the conditions accompanying the precipitation. After a long absence of rains or snowfall, the water collected as a result of the first precipitation will be more mineralized than in subsequent precipitations, since the first precipitation removes from the air the substances suspended therein. For this reason, the troposphere near the earth will have become cleaner during later precipitations. The less precipitation, the higher its mineralization. The time of year, air temperature, previous weather and wind direction also are significant. Finally, the amount of dry impurities in air, which are washed away or trapped by rain water or snow, depends on the height of the clouds that produce the precipitation (G. A. Maksimovich, 1949, 1950 1953, 1955).

Without examining the cases of artificial atmospheric pollution by mineral and organic compounds, the dissolved substances in rain or snow may be divided on the basis of origin into three groups: a) substances in cloud water, mainly of marine origin; b) natural substances lifted by air currents from the earth's surface (marine salt, dust particles and mineral salts of the soil, etc.), trapped and washed down as the atmospheric waters pass through the ground troposphere; c) substances that have reached the ground troposphere as a result of the general and technical activity of the population, trapped and washed down by atmospheric precipitation. Above major population centers with an extensive industry, a particularly important role in the pollution of atmospheric waters is played by substances of the third group (c), consisting of discharges from smokestacks of various boiler houses and heating installations, automobile exhaust, all sorts of discharges from industrial plants containing sulfur dioxide, nitrogen oxides and chlorine, etc.

The amount of dust settling in cities from the atmosphere is very substantial. The following amounts (in grams) have been found to settle in Leningrad per month per m^2 of area: in industrial districts of the city, 50; residential districts, 30; park zones, 50; health park districts, 2-5. About 30% of the dust was owing chiefly to products of incomplete fuel combustion (soot and tar), and about 15%, to water-soluble substances (N. M. Tomson, 1955).

No such complete data exist for Perm' for recent years. Only V. A. Ryazanov (1941) determined in 1935 that the soot content of air over the northeastern part of the city amounted to an average of 0.152 mg/m^3 per year, or 1.2×10^{-8} of the volume. The mean monthly smoke content ranged from 0.102 to 0.17 mg/m^3 in winter and from 0.082 to 0.117 mg/m^3 in summer. These are fairly substantial quantities. At the present time, because of the industrial growth, the smoke content and pollution of the atmosphere above Perm' has risen abruptly. Considering that from the standpoint of this index Perm' is entirely comparable to Leningrad, one can tentatively calculate the amount of dust settling from the atmosphere. Taking the average amount of dust settling from the atmosphere per 1 m^2 as 30 g, based on the data of N. M. Tomson for Leningrad (1955), we find that for city area of 690 km^2, about 248,000 tons or almost 100,000 m^3 of dust settles over Perm' per year. Taking as the basis of the calculation the amount of dust settling on 1 m^2 in the park zone of Leningrad, i.e., 15 g/m^2, we find about 50,000 m^3 per year. Considering that the settled dust may again be raised by the wind into the atmosphere and settle down once more, we shall take only 50% of the latter value. Even with this assumption, about 25,000 m^3 of dust per year settles on Perm' from the atmosphere.

The settling of such huge amounts of dust (including products of incomplete fuel combustion) takes place primarily with the aid of rain and snow. Rain and particularly snow purify the city atmosphere mechanically by removing the dust particles, but at the same time they contaminate the streets and open areas of the city.

The chemical composition of atmospheric precipitation in Perm' has not been studied before our work. Our investigations began in 1945, but they initially consisted of incomplete analyses (G. A. Maksimovich, 1960).

Table 1

Chemical Analyses of Water Obtained from the Melting of Snow Collected in Perm' in 1954
(Analyst V. A. Perlovich)

No.	Place Where Snow Sample Was Taken	Date	pH	1 Liter contains, in mg								
				HCO_3	SO_4	Cl	Ca	Mg	Na	NO_2	NH_4	Total Mineralization
1	Botanical garden. Central part. Old snow.	23 February	6,6	22,3	55,2	15,3	24,0	7,3	2,4	0,07	4,5	131,1
2	Same location, fresh snow three days after snowfall.	6 March	7,4	44,5	14,9	15,3	16,8	5,9	3,5	0,15	3,75	104,7
3	Around the university campus. Old snow, top layer	26 February	6,8	22,3	84,5	23,2	24,0	14,6	8,4	0,15	3,75	180,8
4	University yard, around smokestack. Fresh snow.	3 March	7,0	22,2	3,4	15,3	7,2	4,4	3,4	0,02	0,18	56,1
5	Roof of university. Old snow.	12 March	6,2	22,3	84,0	23,0	26,4	10,3	8,0	0,07	4,5	178,7
6	Same location, fresh snow	18 March	7,0	22,3	43,7	23,2	24,0	7,3	2,8	0,1	7,0	130,4
7	Roof of university, north side. Flow of melting snow.	10 March	6,6	22,3	26,4	15,3	14,4	5,8	3,4	0,15	3,0	90,7
8	Same location, west side	11 March	6,6	22,3	26,4	15,3	12,0	7,3	3,4	0,15	3,5	90,4
9	4 Ovrazhnaya Street (Yegoshikha). Old snow.	28 February	6,9	22,3	26,4	30,7	19,2	7,3	5,1	0,06	4,5	115,5
10	Dzerzhinskiy Street. Snow after four-day snowfall.	17 March	7,1	33,4	48,0	15,3	24,0	7,3	4,9	0,1	6,0	139,0

In 1954, several more complete chemical analyses were carried out on snow collected in the area of the university and on Yegoshikha River. They showed (Table 1) that the mineralization of the snow ranged from 56 to 150 mg/l, and that the content of sulfate ion in old snow reached 84.5 mg/l.

The last chemical analyses of atmospheric precipitation were made in 1958. Snow samples were taken in the Botanical Garden of the university from the surface of the ground on 4 January (A) and 18 January (B) and also from rain gauges of the meteorological station: snow and rain on 3-4 March (C) and rain for April to 15 May (D). In the vicinity of Perm', in the village of Frola, the following samples were taken from the rain gauge: snow on 22 February-28 March (E), snow and rain on 28 March-10 April (F), and rain from 7 through 20 May (G) and from 20 through 31 May (H). Results of the analysis of the samples are given in Table 2.

Summation of the precipitation in the rain gauges for a considerable time interval gave the highest mineralization, approaching 240-245 mg/l (points E and F). Analyses of water from the rain gauge in the area of Frola from 22 February through 31 May (points E-H) are particularly indicative. The mineralization of the precipitation for this period decreased from 245.4 to 89.5 mg/l, the content of sulfate ion from 96 to 19.2, chlorine from 17.8 to 5.3, calcium from 20 to 8, sodium from 34.4 to 4.8, iron from 0.3 to 0.1 and ammonium ion from 4 to 1 mg/l.

As the weather becomes warmer, and the combustion of coal, which contains large amounts of pyrite and ash, declines with the approach of spring, the content of sulfates (from pyrite) bicarbonate ion, calcium and iron (from ash) decreases in the precipitation. Apparently, chlorine is also evolved by the combustion of coal, as is the ammonium ion. The presence of organic matter (soot) in the analyzed precipitation appears to result from a change in the exodizability, which also declines toward spring.

The chemical composition of atmospheric precipitation in the settlement of Ust'-Kishert', located far from industrial enterprises, is entirely different.

Here rain water collected on the school ground in the summer of 1955 was analyzed (by Ye. A. Ashikhmin). Its total mineralization did not exceed 15 mg/l, and the following ions were determined: bicarbonate (8 mg/l), calcium (4 mg/l) and sulfate (3 mg/l). More detailed analyses were performed on samples collected in the same settlement from the roof of house No. 44 on Naberezhnaya Street on 27 June 1958 after a thunderstorm and on 23-25 August 1959 in a glazed pan set out in the garden (Table 3).

In the analysis of 27 June, the substantial amounts of nitrogen compounds observed were probably the result of the washing by the precipitation of the wooden roof on which soot and fine ash had settled during winter,

Table 2

Characteristics of Chemical Composition of Atmospheric Precipitation of Perm' (points A-D) and its Environs - Village of Frola (points E-3) in January-May 1958 (Analyst T. V. Kirillovykh).

Indicators	A	B	C	D	E	F	G	H
Content, mg/1: HCO_3	36,6	36,6	24,4	48,8	61,0	61,0	61,0	42,7
SO_4	16,4	48,0	33,6	19,2	96,0	96,0	57,6	19,2
Cl	7,1	3,5	3,5	7,1	17,8	14,2	7,1	5,3
NO_3	0,5	1,3	10,3	4,8	2,1	3,4	1,4	1,0
NO_2	0,03	0,1	0,1	0,2	0,07	0,6	0,05	0,07
Ca	6,8	18,2	4,4	10,0	20,0	20,0	16,0	8,0
Mg	6,4	7,2	5,1	7,3	9,7	12,2	9,7	7,3
NH_4	1,0	1,2	0,4	1,5	4,0	3,0	2,0	1,0
Na	5,5	3,4	13,3	6,5	34,4	29,7	16,5	4,8
Fe	—	1,0	0,1	0,3	0,3	0,2	0,1	0,1
Total mineralization, mg/1	80,1	119,6	98,1	105,7	245,4	240,3	171,4	89,5
pH	6,9	7,2	6,2	6,8	7,2	6,9	6,9	6,7
Oxidizability, mg of O_2	—	—	3,1	10,0	16,0	13.6	5.6	6,4
Predominant component	HCO_3	HCO_3	SO_4	HCO_3	SO_4	SO_4	HCO_3	HCO_3

when firewood was used for heating. The second August sample was taken with more precautions. However, even then the mineralization of the precipitation for the rural area was still high, 51.6 mg/1. If the nitrate ion and sodium, which were not determined analytically, are excluded from the calculation, and are calculated by difference, the mineralization of the rain water collected on 23-25 August 1959 was approximately 20 mg/1. This figure is closer to the actual value.

Table 3

Characteristics of Chemical Composition of Atmospheric Precipitation in Ust'-Krshert' Village (Analyst T. V. Kirillovykh).

Indicators	27 June 1958 r.	23—25 August 1959 r.
Content, mg/1: HCO_3	36,6	9,2
SO_4	—	4,0
Cl	1,4	3,6
NO_3	41,3	20,9
NO_2	0,1	0,03
Ca	4,2	2,0
Mg	6,1	0,6
NH_4	6,0	0,8
Na	5,3	10,5
Fe	нет	нет
Total mineralization	101,0	51,6
pH	6,6	6,2
Oxidizability, mg O_2	12,3	4,3

Some Conclusions

The atmospheric precipitation in the region of the city of Perm' is characterized by a mineralization from 56 to 245 mg/l, the highest indices pertaining to the winter period for snow. The sulfur, bicarbonate and calcium ions predominate in the precipitation. The first ion is owing to the combustion of carbon with a considerable pyrite content, and the other two, to its high ash content. In addition, products of incomplete fuel combustion are observed in Perm'. They all have relatively little influence on the chemical composition of atmospheric precipitation, but form over the city a smoke screen that remains suspended at different heights depending on the state of the weather, particularly the wind, barometric pressure and air humidity. It must be borne in mind that this smoke screen absorbs sunlight, particularly ultraviolet rays, which are of major biological importance for the health of the population and the growth of vegetation.

According to preliminary calculations, each year 25-50 thousand m^3 of dust settle on the territory of the city. Its presence in the atmosphere above the city accounts for the high mineralization of atmospheric precipitation. Dust combined with gases has an increased irritating effect on the respiratory organs.

Protection of public health requires a persistent struggle with smoke pollution and a systematic control of atmospheric pollution. Conversion to gas heating, introduction of a district heating system, a smokeless process of fuel combustion, systematic sprinkling of streets, planting of greenery, and other measures that have been started in Perm' and are being carried out on an increasing scale will insure a reduction of the smoke pollution of the city.

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Izdanie Ofitsial'noe

Gosudarstvennyy Komitet Soveta Ministrov SSSR Po Delam Stroitel'stva
(Gosstroy SSSR)

INSTRUCTIONS FOR CALCULATING THE ATMOSPHERIC DISPERSAL OF NOXIOUS SUBSTANCES (DUST AND SULFUR DIOXIDE) PRESENT IN INDUSTRIAL EMISSIONS

SN369-67

(Ukazaniya po Raschetu Rasseivaniya v Atmosfere Vrednykh Veschestv
[Pyli i Sernistogo Gaza] Sodérzhaschikhsya v Vybrosakh Promyshlennykh Predpriyatiy
SN369-67)

Approved by the State Committee of the Council of Ministers
of the USSR for Construction Affairs
on 5 June 1967

Gidrometeorologicheskoe Izdatel'stvo
Leningrad, 1967

State Committee of the Council of Ministers of the USSR for Construction Affairs (Gosstroy SSSR)	Construction Standards	SN 369-67
	Instructions for Calculating the Atmospheric Dispersal of Noxious Substances (Dust and Sulfur Dioxide) Present in Industrial Emissions	—

1. General Aspects

1.1. The present Instructions were prepared as an extension of the chapter of SNiP II - G. 7-62 entitled "Heating, Ventilation and Air Conditioning. Project Standards" and "Sanitary Standards for Planning Industrial Enterprises" (SN245-63).

1.2. The requirements of the present Instructions extend to calculations of atmospheric dispersal of noxious substances (dust and sulfur dioxide) present in the emissions of industrial enterprises (facilities) and boiler houses enumerated in Appendix 1.

In agreement with the Main Sanitary-Epidemiological Administration of the Ministry of Health of the USSR, the present Instructions can be used in calculations of atmospheric dispersal of other noxious substances and for other facilities.

1.3. The procedure for calculating the dispersal of noxious substances in the atmosphere is based on the determination of the concentrations of these substances in the ground layer of air.

The degree of danger posed by pollution of the ground layer of air with emissions of noxious substances from industrial enterprises and boiler houses is determined from the largest value of the ground concentration of the noxious substances c_m which can be established at a certain distance from the emission source under unfavorable weather conditions (when the wind velocity reaches a dangerous value and a vigorous vertical turbulent exchange takes place).

Submitted by the Main Administration of the Hydro-meteorological Service of the Council of Ministers of the USSR	Approved by the State Committee of the Council of Ministers of the USSR on Construction Affairs, 5 June, 1967	Date of Introduction, 1 October 1967

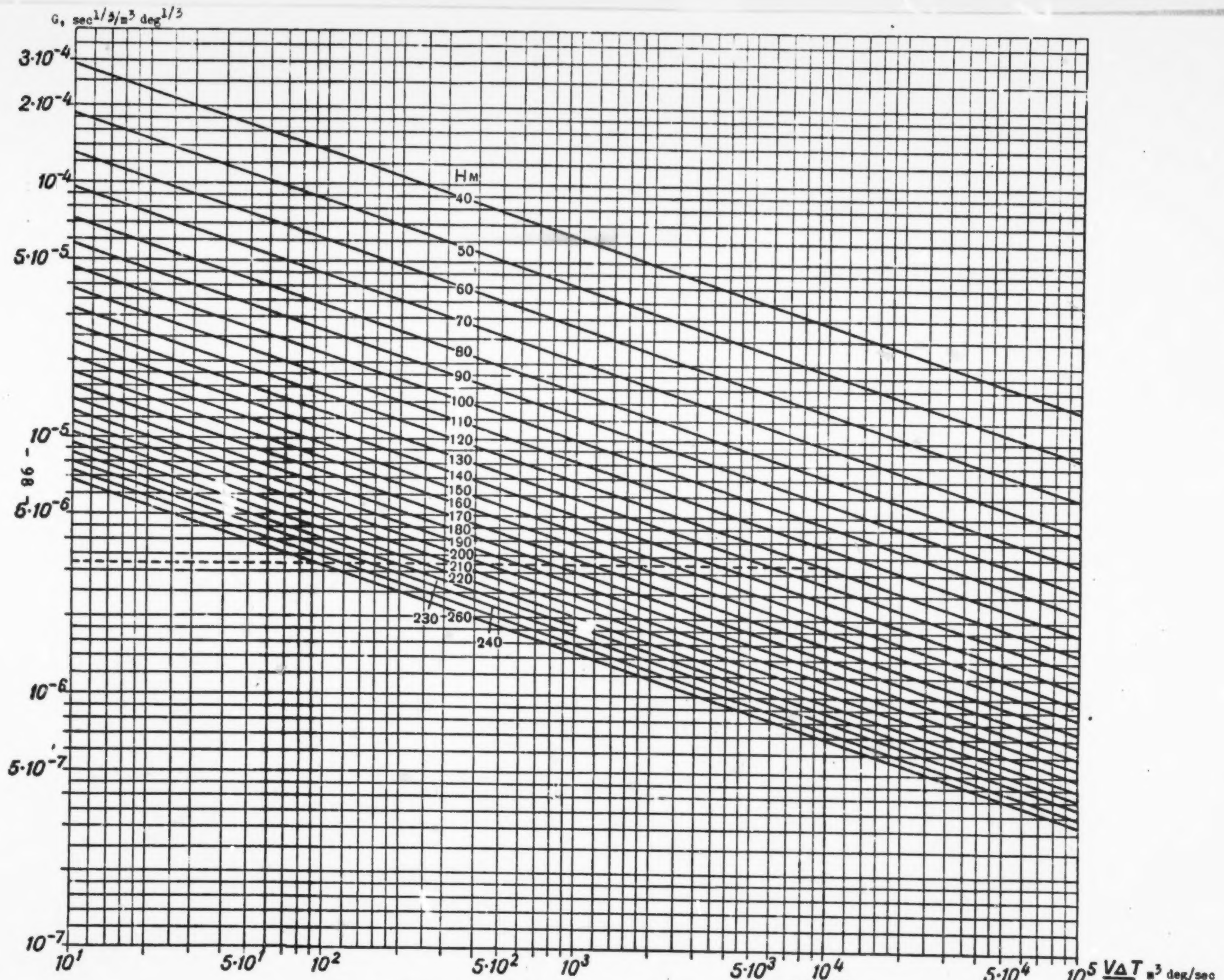

Fig. 1. Nomogram for determining the auxiliary quantity $G = \frac{1}{H^2}\sqrt[3]{\frac{N}{V\Delta T}}$.

The procedure for calculating the dispersal of noxious impurities in the atmosphere extends to organized discharges (through smokestacks) of these substances past purification devices and without purification in cases where the latter is permitted by the sanitary standards. The procedure does not extend to ground-level emission sources.

1.4. The values of c_m (in mg/m^3) for each noxious substance must not exceed the highest one-time maximum permissible concentrations of these substances in the atmosphere (MPC):

$$c_m \leqslant MPC \qquad (1)$$

Remarks:

1. The MPC values should be adopted on the basis of standards approved by the Main Sanitary-Epidemiological Administration of the Health Ministry of the USSR.

2. The one-time MPC's usually refer to a twenty-minute time interval. For this reason, the formulas and graphs given in the present Instructions for determining the concentrations of noxious substances also refer to a twenty-minute time interval.

3. The one-time MPC's currently are the chief characteristic of the danger of substances having no cumulative noxious effect.

4. For sulfur dioxide and nontoxic dust, the one-time MPC's are taken equal to 0.5 mg/m^3.

2. Procedure for Calculating the Dispersal of Emissions for a Single Source

2.1. The value of the maximum ground concentration of a noxious substance c_m (in mg/m^3) emitted by a single emission source under unfavorable weather conditions should be determined from the formula

$$c = \frac{AMFm}{H^2 \sqrt[3]{V \Delta T}}, \qquad (2)$$

where A is a coefficient dependent on the thermal stratification of the atmosphere, which determines the conditions of vertical and horizontal dispersal of noxious substances in air (taken according to § 2.2 of the present Instructions) (in $sec^{2/3}\ deg^{1/3}$);

M is the amount of noxious substance discharged into the atmosphere (in g/sec);

H is the height of the emission source (stack) above ground level (in m);

V is the volume of the gas-air mixture discharged (in m^3/sec).

The volume of the gas-air mixture discharged into the atmosphere is related to the diameter of the aperture of the emission source (stack) D (in m) and to the average exit velocity w_0 (in m/sec) of this mixture from the aperture by the expression

$$V = \frac{1}{4} \pi D^2 w_0; \qquad (3)$$

ΔT is the difference between the temperature of the gas-air mixture discharged T_g and the temperature of the surrounding atmospheric air T_a (in °C.);

F is a dimensionless coefficient allowing for the rate of deposition of the noxious substances in the atmosphere;

m is a dimensionless coefficient allowing for the conditions in which the gas-air mixture leaves the mouth of the emission source.

To simplify the determination of c_m, formula (2) is transformed to the following form:

$$c_m = AMFmG. \qquad (4)$$

The value of G (in $sec^{1/3}/m^3\ deg^{1/3}$) is determined with the aid of the nomogram given in Fig. 1 from values of $V\Delta T$ and H. To this end, from the point of the horizontal coordinate axis corresponding to a given value of $V\Delta T$ is drawn a vertical to the intersection with one of the oblique lines corresponding to the geometric height of the source H. From the point of intersection, a perpendicular is dropped onto the vertical coordinate axis, and the value of G is taken from the latter. As an example, Fig. 1 shows the determination of G with a dashed line for $H = 120$ m and $V\Delta T = 10^4\ m^3$ deg/sec. For such parameters, G turns out to be equal to $3.25 \times 10^{-6}\ sec^{1/3}/m^3\ deg^{1/3}$.

2.2. The coefficient A is taken for unfavorable (unsafe) weather conditions, when a vigorous vertical turbulent exchange is taking place. At the same time, the ground concentration in air of noxious substances discharged from a high source reaches its maximum value.

The following values of the coefficient A should be taken in the calculations:

(a) for Central Asia, Kazakhstan, the Lower Volga region, Caucasus, Siberia, and Far East, 200;

(b) for the north and northwest of the European territory of the USSR, Middle Volga Region, Urals, and Ukraine, 160;

(c) for the central part of the European territory of the USSR, 120.

Remarks:

1. In other areas, the values of the coefficient A should be taken by analogy with the climatic conditions of turbulent exchange in these areas and those indicated in the present paragraphs.

2. The applicability of the present Instructions is limited by a condition according to which the parameter

$$f = \frac{10^3 w_0^2 D}{H^2 \Delta T}, \qquad (5)$$

determined on the basis of data on w_0, D, H and ΔT should satisfy the inequality $f < 6$ (f in m/sec^2 deg). Accordingly, the Instructions do not extend to the calculation of the atmospheric dispersal of emissions with temperature T_g of the gas-air mixture close to the temperature of the ambient air T_a.

3. The values of the concentrations of the noxious substances, calculated on the basis of the present Instructions, pertain to steady conditions of propagation of an impurity remaining in the atmosphere above flat or slightly broken ground. When enterprises are planned on broken ground, one should request special instructions for calculating the dispersal of noxious substances in the atmosphere from the A. I. Voyeykov Main Geophysical Observatory of the Main Administration of the Hydro-meteorological Service, Council of Ministers of the USSR, and from the Main Sanitary-Epidemiological Administration of the Health Ministry of the USSR. It is recommended that large-scale discharges of noxious substances in areas of stagnation of air should be avoided, and also in areas with frequent fogs or elevated temperature inversions.

2.3. In the presence of unfavorable local characteristics of the meteorological regime, according to the available scientific and industrial experience, the value of the ground concentrations of noxious substances should be increased by 25%.

2.4. The values of M and V are determined in conformity with the standards in force for the given enterprise, by M being meant the amount of noxious substance contained in the gas-air mixture past the purification equipment. In this case, in carrying out the calculation one should take into account the maximum values of M and minimum values of V which can arise under certain technological conditions of operation of the enterprises.

Comments:

1. When raw material and fuel with different sulfur and ash indices are used, the largest values of these quantities should be employed in the calculations.

2. In establishing the necessary degree of removal of noxious substances from the emissions, one should take the actual values of the efficiencies of the purification equipment under ordinary operating conditions.

2.5. In determining the difference ΔT between the temperature of the discharged gas-air mixture T_g and the temperature of the ambient air T_a, the temperature of the ambient air taken is the average temperature of the warmest month at 1 P.M., indicated in the chapter of SNiP II-A.6-62 entitled "Construction Climatology and Geophysics. Basic Principles of Planning" (Table 1, column 18).

Comment. For boiler houses operating according to the thermal graph, it is permitted in the calculations to take as values of T_a the average temperatures of the heating period according to the chapter of SNiP II-A. 6-62 (Table 1, column 23).

2.6. In determining the concentrations of noxious substances, the following values of the dimensionless coefficient F should be taken:

(a) for sulfur dioxide and other noxious substances for which the settling rate is practically equal to zero, equal to 1;

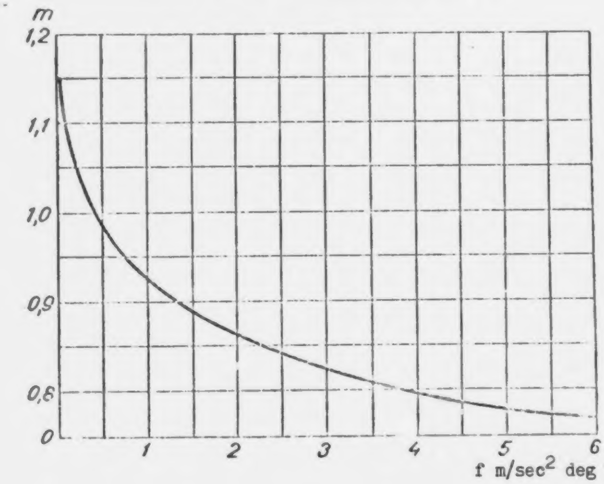

Fig. 2. Graph for determining the coefficient m, considering the conditions of discharge of the gas-air mixture from the source orifice.

(b) for dust, if the operational purification coefficient is

not less than 90%, equal to 2;
less than 90%, equal to 2.5.

2.7. The value of the dimensionless coefficient m allowing for the conditions of discharge of the gas-air mixture from the orifice of the emission source (stack) should be determined from the value of the parameter $f = \frac{10^3 w_0^2 D}{H^2 \Delta T}$ (in m/sec^2 deg) with the aid of the graph of Fig. 2.

2.8. The maximum concentration of noxious substances near the surface of the ground under unsafe weather conditions c_m is reached on the plume axis of the discharge (along the direction of the average wind for the period considered) at a distance x_m (in m) from the source, a distance determined in units of height of the discharge source (stack) H, and is found approximately from the formula

$$x_m = 20H. \tag{6}$$

Comment. Concentrations of noxious substances differing from the maximum concentration by not more than 30% are observed at distances in the range of (10-40) H. Care should be taken that the zones of maximum concentrations of noxious substances do not coincide with densely populated quarters or with areas where medical or children's institutions are located.

2.9. The unsafe wind velocity u_m (in m/sec) at the wind vane level (usually, 10 m from ground level) at which the highest value of the ground concentration of the noxious substances in air is reached, should be approximately determined from the formula

$$u_m \simeq 0{,}65 \sqrt[3]{\frac{V \Delta T}{H}}. \tag{7}$$

The explanation of the symbols entering into the above formula is given above.

The value of u_m can also be determined by using the nomogram given in Fig. 3, from values of $V\Delta T$ and H. For this purpose, from the point on the horizontal coordinate axis corresponding to the given value $V\Delta T$ is drawn a vertical to the intersection with this line of the family of oblique lines corresponding to the geometric height of the source H. Then from the point of intersection is dropped a perpendicular to the vertical axis on which the value u_m is determined.

Comment. More precise calculations show that the calculated unsafe wind velocity u_m is slightly higher than that calculated from formula (7) and depends on the parameter given above, f. When $f < 1$, the unsafe velocity is approximately 10% higher, and when $1 < f < 6$, approximately 20% higher.

2.10. The maximum value of the concentration c_{mu} (in mg/m^3) of noxious substances in the ground layer of air under unfavorable weather conditions and at a wind velocity u different from u_m is approximately determined from the formula

$$c_{mu} = r c_m. \tag{8}$$

The dimensionless quantity r is then found from Fig. 4 as a function of the ratio u/u_m (curve r).

The distance from the source $x_{m\mu}$ (in m) at which for a wind velocity u and under unfavorable weather conditions the ground concentration of noxious substances reaches the maximum value $c_{m\mu}$ is determined from the formula

$$x_{mu} = p x_m . \qquad (9)$$

The dimensionless quantity p is also found from Fig. 4 as a function of the ratio u/u_m (curve p).

2.11. The distribution of the concentrations of noxious substances in the atmosphere along the axis of the discharge plume c (in mg/m^3) at various distances x (in m) from the source is calculated from the formula

$$c = s_1 c_m, \qquad (10)$$

the dimensionless quantity s_1 at the unsafe wind velocity being found from the ratio x/x_m on the graph shown in Fig. 5. For gaseous noxious substances, s_1 is taken from the solid curve. For dust, s_1 is also determined from the solid curve at distances $x < 2x_m$. For higher values of x, the dust concentrations decrease faster, and the value of s_1 in this case is taken from the dashed curve in the same figure.

Comment. The concentrations of noxious substances at various distances along the direction of the wind are similarly determined in the case of other wind velocity values under unfavorable weather conditions. The value of $x_{m\mu}$ is then determined first from Fig. 4 and formula (9). Then, s_1 is found by plotting $x/x_{m\mu}$ instead of x/x_m along the horizontal axis of Fig. 5. To obtain the concentration c, $c_{m\mu}$ is multiplied by s_1.

2.12. Values of the concentrations of noxious substances in the atmosphere (in mg/m^3) at a distance y (in m) from the plume axis (measured along the perpendicular to the direction of the average wind) are determined from the formula

$$c_y = s_2 c, \qquad (11)$$

where c is the concentration of the impurity on the axis of the discharge plume, determined from formula (10). The dimensionless quantity s_2 is found from Fig. 6 as a function of the ratio y/x.

2.13. The minimum permissible height of emission of noxious substances (stack height) H (in m) at which a value of c_m equal to the MPC is ensured is calculated from the formula

$$H = \sqrt{\frac{AMFm}{\mathrm{MPC}\ \sqrt[3]{V \Delta T}}} . \qquad (12)$$

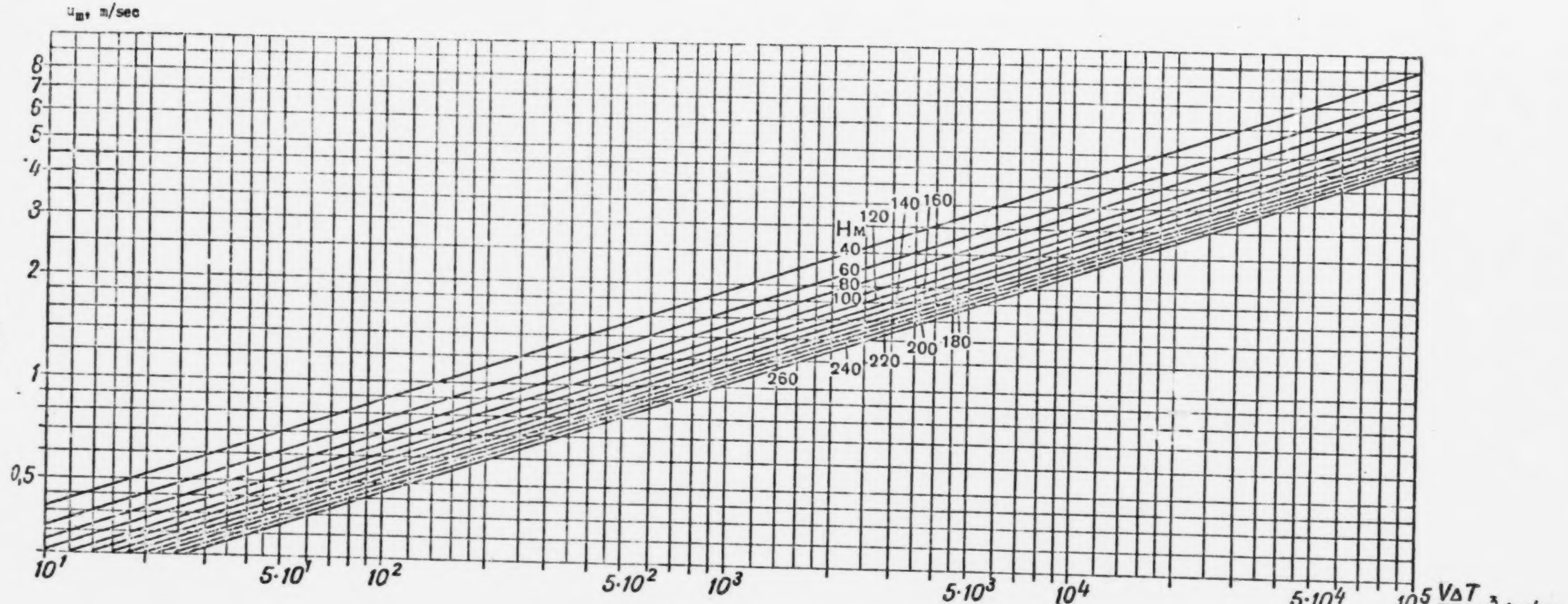

Fig. 3. Nomogram for determining the unsafe wind velocity u_m.

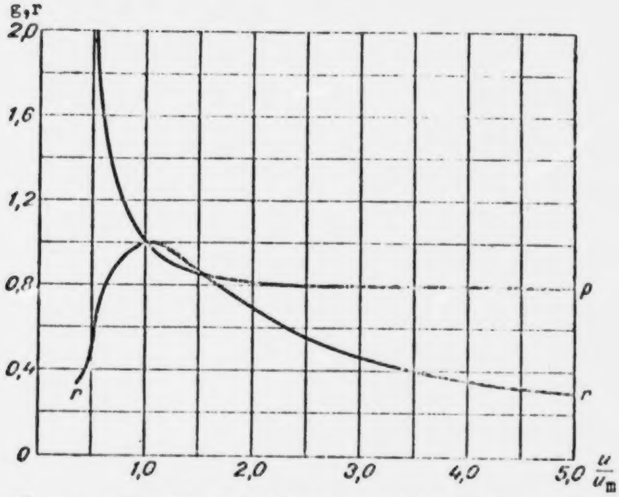

Fig. 4. Graph for determining the auxiliary values r and p used for calculating the concentrations under unfavorable weather conditions and at wind velocity u different from u_m.

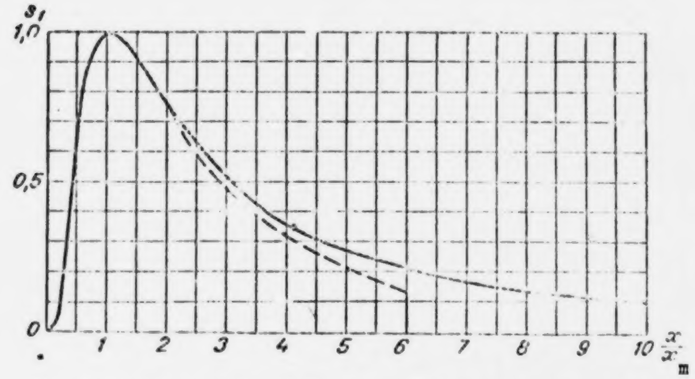

Fig. 5. Graph for determining the auxiliary values s_1 used for calculating the ground concentrations on the axis of the discharge plume at various distances from the source.

The symbols of the quantities entering into the formula are described above.

Here it is assumed that m = 1 to a first approximation. From the value of H thus obtained, the coefficient m is determined in the manner indicated above (see § 2.7 of the present Instructions). The value of m obtained is substituted into formula (12), and a more accurate calculation of the stack height H is carried out.

Comments:

1. If there exists a single source of discharge of several different noxious substances, its height should be determined from the highest value of H obtained from formula (12) for each individual noxious substance. In particular, if

$$FM_{SO_2} > FM_d, \tag{13}$$

H is determined from the discharge of sulfur dioxide M_{SO_2}; and for

$$FM_{SO_2} < FM_d \tag{14}$$

H is determined from the discharge of dust M_d.

2. The absence of impurities on the territory of industrial facilities and in the residential areas located in the immediate vicinity to this territory is promoted by the discharge of noxious substances at a height H that is not less than 2.5 times the height of buildings adjacent to it within a radius of 4.5 H.

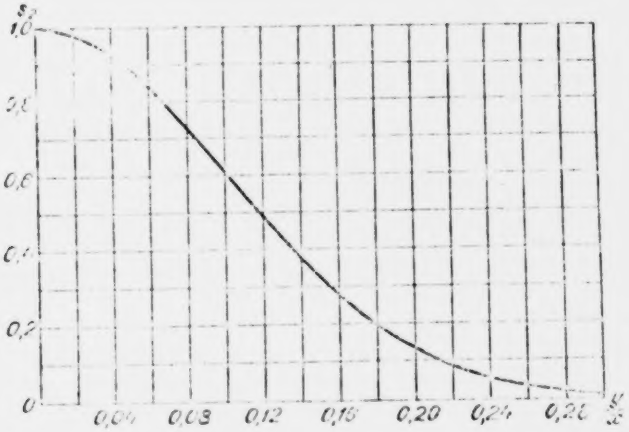

Fig. 6. Graph for determining the auxiliary value s_2 used for calculating concentrations at points not located on the axis of the discharge plume.

2.14. The maximum permissible discharge (MPD) (in g/sec) of noxious substances into the atmosphere for which a pollution of the ground layer of air not in excess of MPC is achieved is calculated from the formula

$$\text{MPD} = \frac{\text{MPC} \cdot H^2 \sqrt[3]{V \Delta T}}{AFm}. \tag{15}$$

Here the concentration of impurities in the emissions past the purification equipment must not exceed the value

$$C_{ms} = \frac{\text{MPD}}{V} \tag{16}$$

or, considering formula (15),

$$c_{ms} = \frac{\text{MPC} \cdot H^2}{AFm} \sqrt[3]{\frac{\Delta T}{V^2}}. \tag{17}$$

2.15. When noxious substances are discharged into the atmosphere as a result of the combustion of fuel, the maximum permissible fuel consumption (MPF) (in t/hr) is determined from the formula

$$\text{MPF} = 3{,}6 H^3 \sqrt{\left(\frac{\text{MPF}}{d_1 AFm}\right)^3 d \Delta T}, \tag{18}$$

where d is the amount of gas-air mixture discharged per unit weight of fuel (in m^3/kg);

d_1 is the amount of noxious impurity discharged into the atmosphere per unit weight of fuel (in g/kg).

3. Procedure for Calculating the Dispersal of Emissions for a Group of Sources

3.1. For a group of emission sources standing close to each other (the distance between the extreme sources does not exceed 3-4 average source heights above the surface of the ground), the sources may be practically assumed to be located at a single point that is the center of the site on which they are located.

When the output of one of the emission sources is much larger than that of the others, the sources may be assumed to be located at a single point coinciding with the location of the source.

3.2. If the discharge of noxious substances is uniformly distributed among N sources located close to each other and having the same heights and aperture diameters, the total value of the maximum concentration c_m is determined from the formula

$$c_m = \frac{AMFm}{H^2} \sqrt[3]{\frac{N}{V\Delta T}}, \qquad (19)$$

where M is the total amount of the given noxious substance discharged from all the sources (in g/sec);

V is the total volume of the gas-air mixture discharged from all the sources (in m^3/sec).

The remaining symbols are given in section 2.

The volume of the gas-air mixture is related to the number of emission sources, the diameter of their aperture and the average exit velocity of the gas-air mixture by the following relation:

$$V = \frac{1}{4} \pi D^2 w_0 \cdot N. \qquad (20)$$

The unsafe velocity u_m (in m/sec) in this case is approximately determined from the formula

$$u_m \simeq 0,65 \sqrt[3]{\frac{V\Delta T}{NH}}. \qquad (21)$$

In the presence of a group of identical emission sources clustered together, formula (4) and the nomograms given in Figs. 1 and 3 can be used to simplify the calculations of c_m and u_m. When these nomograms are used for N identical emission sources, the only difference from the case of a single source is that the point corresponding to $V\Delta T/m$ is marked on the horizontal axis. Otherwise the procedure of calculation for N closely clustered identical emission sources does not differ in any way from the procedure, described in section 2, for calculating the dispersal of noxious substances for a single emission source.

3.3. If a group consisting of N sources has different heights and discharge parameters, then the maximum ground concentrations should first be determined for each source for all the noxious substances, c_m (c_{m1}; c_{m2}; c_{m3};...; $c_{m(N-1)}$; c_{mN}) and unsafe wind velocities u_m (u_{m1}; u_{m2}; u_{m3};...; $u_{m(N-1)}$; u_{mN}).

If for some noxious substance the sum c_m of all the sources turns out to be lower than the MPC, further calculations of the dispersal of this noxious substance in the atmosphere should not be carried out, since in this case the concentrations of this substance will obviously nowhere exceed the MPC.

For each noxious substance for which the sum of all N sources exceeds the MPC, it is necessary to determine the weighted mean unsafe wind velocity $u_{m\ av}$ (in m/sec) for N sources from the formula

$$u_{mav} = \frac{u_{m1}c_{m1} + u_{m2}c_{m2} + \ldots + u_{mN}c_{mN}}{c_{m1} + c_{m2} + \ldots + c_{mN}}. \qquad (22)$$

Further, for each noxious substance at wind velocity $u = u_{mav}$, formulas (8) and (9) and Fig. 4 can be used to calculate the values of c_{mu} and x_{mu} for each source.

Remark. If for any given noxious substance the sum c_{mu} for all the sources is less than the MPC, no further calculations should be carried out, since the concentration of the noxious substance will not exceed the MPC anywhere. In the remaining cases, it is necessary to establish that when $u = u_{mav}$, the field of the total concentration $\bar{c}$ produced by all the sources will not reach values in excess of the MPC anywhere.

3.4. If among N emission sources there are N_1 sources to which small values of c_{mu} correspond for certain noxious substances, the calculations for this substance can be simplified by slightly raising the estimate of the air pollution caused by the enterprise.

For this purpose, it is first necessary to determine the sum of maximum concentrations c_{mu} for all of the N_1 sources and determine the difference between the MPC and the sum. Then an estimate is made of the maximum total concentration for the remaining $N-N_1$ sources; this concentration should never exceed the calculated difference between the MPC and the sum of c_{mu} anywhere.

3.5. If sources with different emission parameters are located close to each other and, according to § 3.1, can be reduced to a single point, the calculation of the total concentration for each noxious substance is carried out as follows. For each source, a plot is made of the curves representing the change of the concentration c with the distance x at wind velocity $u = u_{mc}$, calculated from formula (22). Then all the curves are plotted on a single graph with a common origin of coordinates. For the same distances x, the c values from all the stacks are summed up, and the total values of $\bar{c}$ are found as a function of the distance x. The highest $\bar{c}$ value will be the maximum concentration of the given noxious substance for all the discharges, and the distance, measured from the origin, at which the maximum total concentration is reached can be taken as x_m.

Comment. The procedure for calculating the total air pollution for the case where a group of sources with different emission parameters can be reduced to a single point is treated in detail in Appendix 2 (Example 6).

3.6. In the case where a straight line can be drawn in any direction through the main sources of emission of noxious substances plotted on a plan (contour map), so that the distance from the individual sources to the given straight line does not exceed 1.5-2 average heights of the emission sources, they can be shifted to this line in the calculation. Next, at wind velocity $u = u_{mc}$, calculated from formula (22), c_{mu}, x_{mu} and curves of distribution of c from x are calculated. These curves for all the N sources are then plotted on a graph with a common coordinate axis x. The origin of each curve coincides with the corresponding source successively plotted on axis x, the scale being taken into account.

The graph should be plotted for two variants. In one it is assumed that the wind is directed from the first to the N-th source, and in the other, in the opposite direction. Then, a graphical addition is made for the different distances, values of the total concentration $\bar{c}$ are calculated, and the highest ones are taken as the maximum concentration c_m.

Comments:

1. In particular, the indicated method should be used for calculations in the presence of two sources (or two groups of neighboring sources) located far from one another.

2. As an example, let us make the calculation for the case of two sources discharging sulfur dioxide into the atmosphere. The height of the first source H = 50 m, $c_{m1} = 0.30$ mg/m^3, $u_{m1} = 3$ m/sec; for the second source, the height H = 120 m, $c_{m2} = 0.35$ mg/m^3, and $u_{m2} = 6$ m/sec. The distance between the sources is 6 km.

The weighted-mean unsafe wind velocity u_{mav} should be calculated in accordance with formula (22)

$$u_{mav} = \frac{3 \cdot 0,30 + 6 \cdot 0,35}{0,30 + 0,35} = 4,6 \text{ m/sec.}$$

From formulas (8) and (9) and Fig. 4 we find that when $u = u_{mav}$, for the first source $c_{mu1} = 0.26$ mg/m^3 and $x_{mu1} = 900$ m, and for the second source $c_{mu2} = 0.32$ mg/m^3, and $x_{mu2} = 3700$ m. The sum c_{mu} from both sources is greater than the MPC for sulfur dioxide (0.5 mg/m^3), and it is therefore necessary to carry out a graphical addition of the axial concentrations (for $y = 0$).

Figure 7 illustrates the graphical addition for two variants, when the wind is directed from the first source to the second (a), and vice versa, from the second source to the first (b). The highest concentration is observed when the wind is directed from the second source to the first. Then c_m is 0.5 mg/m^3, and the value of x_m, measured from the second source, is 7000m.

3.7. In general, when all the emission sources cannot be reduced to a single point or placed on a common straight line, the calculations should be carried out as follows.

On a plan (contour map) of the area representing the arrangement of the atmospheric pollution sources, a straight line is drawn so that the sum c_m from sources located at distances from this line of not more than (1.5-2)H is the largest. This line should be taken as axis x.

In some cases it is sufficient to carry out a graphical summation of the concentrations of noxious substances from emission sources along a given line, assuming that the wind is directed along the latter and the neighboring sources are brought down to this line; in taking into account the influence of the remaining sources, formula (11) and Fig. 6 should be used.

In the remaining cases, from each source lines should be drawn connecting it to the other sources. It is then successively assumed that the wind blows along these lines, and the total concentrations are calculated at points where maximum concentrations of noxious substances from sources located on these lines are reached.

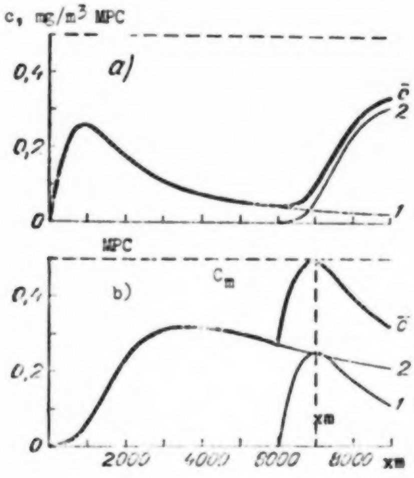

Fig. 7. Example of calculation of the maximum ground concentration of sulfur dioxide for two sources located on a single straight line.

Comment. If the volume of the necessary calculations is large and a greater accuracy of the calculations is required, it is expedient to use electronic computers. At the same time, a calculation of the concentrations for the coordinate grid of the points should also be carried out. In the case where there is a predominant emission source of a given noxious substance, the origin of coordinates is made to coincide with it. If several sources emit approximately the same (comparable) amount of impurity into the atmosphere, the origin of coordinates is placed approximately at the center of their location. The concentrations of the impurity are then determined at the points of the grid from each of the sources according to the above-indicated procedure, taking into account the concentration change across the plume axis. The calculations should be made successively for the possible wind directions along the eight points of compass. For each wind direction, the summation of the concentrations from all the sources is made at the points of the grid.

From the values of the total concentration $\bar{c}$ obtained, the highest value is chosen, which is taken to be c_m, and the point to which this concentration refers is plotted.

4. Consideration of the Background Concentration of Noxious Substances

4.1. In planning new industrial enterprises and boiler houses with discharges of noxious substances in an area where the atmospheric air is polluted with the same noxious substances from other industrial facilities and also when expanding industrial enterprises and boiler houses, it is necessary to consider the initial or background concentrations of the noxious substances in atmospheric air c_b (in mg/m^3).

The sum of the maximum and background concentrations for each noxious substance should not exceed the MPC.

Comment. It is necessary to consider the possibility of the joint presence of sulfur dioxide and sulfuric acid (H_2SO_4) aerosol in the air. In this case, the following condition should be fulfilled:

$$c_{m\,SO_2} + c_{b\,SO_2} \leq MPC_{SO_2}\left(1 - \frac{c_{b\,H_2SO_4}}{MPC_{H_2SO_4}}\right), \tag{23}$$

where $MPC_{H_2SO_4} = 0.3$ mg/m^3 is the one-time MPC for sulfuric acid aerosol.

4.2. In the presence of background pollution of the atmosphere with noxious substances, the MPC in formulas (12), (15), (17) and (18) should be replaced by values of MPC-c_b.

4.3. In the presence of background pollution, formulas (13) and (14) are transformed to the following form:
when

$$\frac{FM_{SO_2}}{MPC - c_{b\,SO_2}} > \frac{FM_{\text{п}}}{MPC - c_{b,d}} \tag{24}$$

H is determined from the emission of sulfur dioxide M_{SO_2}, and when

$$\frac{FM_{SO_2}}{MPC - c_{b.SO_2}} < \frac{FM_d}{MPC - c_{b,d}} \qquad (25)$$

H is determined from the emission of dust M_d.

Comment. Consideration of the background concentration of noxious substances in the atmosphere is illustrated with Examples 2 and 3 of Appendix 2.

4.4. The value of the background pollution with noxious substances of the air reservoir of the area where the construction of an industrial enterprise or other facility is proposed is determined from data of the Main Sanitary-Epidemiological Administration of the Health Ministry of the USSR and its agencies on the basis of experimental measurements of the concentrations of noxious substances in air.

Comment. The experimental measurements of the concentrations of noxious substances should be made chiefly at points located approximately on a line connecting the location of the projected facilities with the center of the location of the heaviest existing sources of atmospheric pollution when the wind is directed along this line.

4.5. If the Main Sanitary Epidemiological Administration of the Health Ministry of the USSR and its agencies lack the experimental data on the background concentration of noxious substances in the atmosphere, this concentration must be calculated. To this end, it is necessary to calculate the distribution of the total concentration of noxious substances from projected and existing sources by using the procedure described in section 3 of the present Instructions. The calculated concentrations must be refined by using the results of observations at points where the air pollution is also due to unorganized discharges that are not considered in the calculations.

4.6. In calculating the dispersal of noxious substances in the atmosphere, it is necessary to bear in mind that when a new industrial facility is set into operation, the general air pollution level is raised, and in the vicinity of industrial enterprises built earlier, the concentrations of noxious substances in the atmosphere may exceed the MPC, something that was not observed earlier. Thus it is necessary, on the basis of the calculations, to evaluate the changes of the maximum concentration of noxious substances in the air for other enterprises, taking into account the additional air pollution caused by the industrial facility under construction when the wind is blowing on them from the direction of the latter.

5. Recommendations for Protection of the Air Reservoir During Operation of Industrial Enterprises and Boiler Houses

In order to maintain the necessary purity of the air reservoir during the operation of industrial enterprises and boiler houses, the explanatory notes and the construction for modernization plans for these facilities should indicate the set of measures whose implementation during the period of operation will ensure the conditions of atmospheric dispersal, established by calculations, of the noxious substances present in the emissions of these industrial enterprises and boiler houses.

5.1. In the operation of industrial enterprises and boiler houses it is necessary that the emissions of noxious substances from the individual sources into the atmosphere do not exceed the maximum permissible emissions (MPE).

The concentrations of noxious substances in the gas-air mixture discharged into the atmosphere should not exceed the c_{ms} values determined from the formulas given above (see § 2.14 and 4.2 of present Instructions).

It is recommended that provisions be made for installing instruments for recording the concentrations of noxious substances past the purification equipment at large sources of emission of such substances.

5.2. Under particularly unfavorable weather conditions, especially when an elevated temperature inversion several hundreds of meters thick with average temperature gradients of 3-4°C. per 100 m in this layer is located above the smokestacks, and the wind is directed from the emission sources toward residential areas, a heavy and increasing pollution of air with noxious substances being observed in the ground layer (with concentrations of the noxious substances in excess of the maximum permissible ones), the rate of discharge of such substances into the atmosphere should be reduced as much as possible at industrial enterprises and other facilities according to the requirement of the agencies of the Main Sanitary-Epidemiological Administration of the Health Ministry of the USSR.

5.3. Under unfavorable weather conditions at industrial plants and other facilities, control of the maximum utilization of purification equipment at the main sources of atmospheric pollution should be set up, reserve fuel and raw material with the lowest sulfur and ash content should be used, one-time emissions of noxious substances should be discontinued, and other steps reducing the emissions of noxious substances into the atmosphere should be taken.

5.4. For each industrial district, for major industrial enterprises and boiler houses, plans should be worked out to reduce the emissions of noxious substances into the atmosphere and to control them under unfavorable weather conditions, based on a systematic collection of data on the discharge parameters of noxious substances and also a combined analysis of meteorological data and data on atmospheric pollution.

6. Determination of Boundaries of the Sanitary-Protective Zone

6.1. In conformity with the "Sanitary Standards for Planning Industrial Enterprises" (SN245-63), industrial enterprises (facilities) should be separated from residential areas by sanitary-protective zones (gaps).

The length of a sanitary-protective zone l_0 (in m) for different categories of enterprises and facilities is established in the case where there is no marked predominance of winds of definite directions.

6.2. When the mean annual wind rose is substantially different from circular, i.e., for a wind frequency p of certain directions (for an eight-point wind rose) substantially greater than the average value of p_0 ($p_0 = \frac{100\%}{8} = 12.5\%$), the length of the sanitary-protective zone should be corrected by allowing for the characteristics of the wind regime of the area where the facility is located.

For these wind directions, the length of the gap l (in m) measured from the industrial facility (source of atmospheric pollution) to the outer boundary of the sanitary-protective zone is given by the formula

$$l = l_0 \frac{p}{p_0}. \tag{26}$$

In directions for which the wind frequency $p < p_0$, it is necessary to assume that $l = l_0$.

6.3. In the case where according to calculations made by using the procedure indicated in the present Instructions the maximum concentration of noxious substances in the atmosphere turns out to be higher than the MPC, and the calculated distance L_0 (in m) up to which the concentration is greater than the MPC exceeds l_0, the distance from the industrial facility (source of atmospheric pollution) to the outer boundary of the sanitary-protective zone should be increased.

For a wind frequency $p < p_0$, the value of l is given by the formula

$$l = L_0 \frac{p}{p_0}. \tag{27}$$

In directions for which the wind frequency $p < p_0$, it is necessary to assume that $l = L_0$.

Comment. The calculation of the length of the sanitary-protective zone is illustrated by Example 6 of Appendix 2.

7. Tabulation of Results of Calculation of Dispersal of Noxious Substances in the Atmosphere

7.1. In tabulating the results obtained by calculating the dispersal of noxious substances in the atmosphere, the plans of industrial enterprises (facilities) and boiler houses with considerable emissions of noxious substances into the atmosphere should be supplemented with a report including the following data:

(a) A plan (contour map) of the construction site with a radius of not less than 100 maximum stack heights from the facility being planned, containing the main sources of noxious substances (taken from master plans) both at the facility being planned, allowing for its possible modernization and expansion, and at other existing or planned enterprises in this area.

The contour map must also show populated areas, areas of planned residential construction, hospitals, sanatoriums, weather stations, and also rivers, water reservoirs, forests, farm lands, etc. Isolines of the same heights are drawn every 20 m.

(b) Tables containing the following data for each air pollution source (the sources should preferably be relabeled):

amount M (in g/sec) of discharged impurities, their chemical composition (as much information as possible is given on the particle size distribution of the dust past the purification equipment);

height H and diameter of the orifice of the emission source D (in M), the volume V (in m^3/sec) of the discharge gas-air mixture;

efficiency of the purification equipment based on projected and operational data.

(c) For every existing and projected industrial enterprise (facility), the character of the impurity is indicated in conformity with the "Sanitary Standards for Planning Industrial Enterprises" (SN245-63), and data on unorganized discharges are given.

(d) A table of the mean annual frequency of winds for the eight principal points of compass, average and average maximum temperatures of air at the level of the instrument shelter for the warmest month on the basis of climatic handbooks and of the chapter of SNiP II-A.6-62 entitled "Structural Climatollgy and Geophysics. Basic Principles of Planning."

For the construction site of the enterprise (facility) it is also recommended that data be given for each month on the average frequency of various gradations of wind velocity, calms, fogs, and ground and elevated (at heights of 100-300 m) temperature inversions. In the absence of necessary data in the chapter of SNiP II-A.6-62 and in climatic handbooks, such data can be obtained from offices of the hydrometeorological service.

Weather stations are indicated from the data of which one can obtain the characteristics of the climatic and weather regime of the area. These weather stations should be marked on the contour map or on a separate map.

(e) Information on a local sanitary-epidemiological station with background concentrations for all the ingredients of noxious impurities, on their concentrations under the plume of the main enterprises (within a radius of 100 source heights), on the toxicity of the noxious substances discharged and on the MPC's established for them. The sanitary-epidemiological service also confirms that all the chief sources of atmospheric pollution have been taken into account in the calculations.

(f) Variants of calculation of the distribution of ground concentrations of noxious substances for different choices of parameters characterizing the output of the enterprise (facility), degree of purification of the emissions, location, height and diameter of the emissions orifice, exit velocity, overheating of the gas-air mixture, etc.

Of these variants, the one that is most efficient and economically justified is selected.

In working out steps to ensure the purity of atmospheric air, it is necessary to consider the cost of construction of connecting lines, air intake tubes, ventilation equipment, organization of the sanitary-protective zone, etc.

(g) Tables and graphs for calculating the distribution of the concentrations of noxious substances around an enterprise (facility) and sanitary-protective zone, determined in accordance with data of the Instructions, patterned after the examples given below (Appendix 2).

7.2. Examples of calculations of the dispersal of noxious substances in atmospheric air and calculations of the sanitary-protective zone are given in Appendix 2.

APPENDIX 1

LIST OF INDUSTRIAL ENTERPRISES AND FACILITIES COVERED BY THE INSTRUCTIONS

1. Sintering ferrous metallurgical plants
2. Plants producing roasted ferrous metal pellets
3. Sintering non-ferrous metallurgical plants
4. Converter shops
5. Blast furnace production
6. Open hearth shops
7. Electric steelmaking shops
8. Production of sulfuric acid by the contact process
9. Production of elemental sulfur
10. Petroleum refining plant (combustion of mazut in units of catalytic reforming, thermal and catalytic cracking, hydrofining, atmospheric pipe stills and atmospheric-vacuum pipe stills, separation and isomerizations of xylene, purification of oils)
11. Boiler houses

APPENDIX 2

EXAMPLES OF CALCULATION OF THE DISPERSAL OF NOXIOUS SUBSTANCES IN THE ATMOSPHERE

Example 1.

Calculation of pollution of the atmosphere with sulfur dioxide and dust in the area of the sintering plant of a ferrous metallurgical enterprise. Construction site, the Urals.

No.	Name, Designation, Formula and Calculation	Units	Value
A.	Calculation of the Amount of Sulfur Dioxide and Dust, Volume and Exit Velocity of Gas-Air Mixture Discharged into the Atmosphere		
1	Area of one sintering belt - F_1	m^2	200
2	Number of sintering belts - n	—	2
3	Type of charge - sulfite ore	—	—
4	Fuel used for igniting the charge - coke oven blast furnace gas	—	—
5	Maximum sulfur content of the charge - S^{ch}	%	0.8
6	Charge desulfuration coefficient - η^{ch}	—	0.95
7	Hydrogen sulfide content of coke oven gas - $(H_2S)^c$	g/nm^3	5
8	Sulfur content of blast furnace gas - S^b	g/nm^3	0.5
9	Amount of charge processed - G^p	t/day	$1.1 \cdot 10^4$
10	Amount of coke-oven gas consumed in igniting 1 ton of charge - $G^1_{i.c}$	nm^3/t	5
	Consumption of blast furnace gas in igniting 1 ton of charge - $G^1_{i.b}$	nm^3/t	40
11	Consumption of coke oven gas in igniting the charge - $G_{i.c}$ $G_{i.c} = \frac{G^1_{i.c} G^p}{24} = \frac{5 \times 1.1 \times 10^4}{24}$	nm^3/hr	2300
	Consumption of blast furnace gas in igniting the charge - $G_{i.b}$ $G_{i.b} = \frac{G^1_{i.b} \times G^p}{24} = \frac{40 \times 1.1 \times 10^4}{24}$	nm^3/hr	18 900
12	Concentration of dust in gases leaving the sintering machines (before purification), - g	g/m^3	3
13	Type of dust-removing unit - battery cyclones, no sulfur removal	—	—
14	Operational value of efficiency of dust removing unit - η_d	%	90
15	Temperature of gas-air mixture at exit from stack - T_g	°C.	150
16	Temperature of ambient air - T_a	°C.	30

No.	Name, Designation, Formula and Calculation	Units	Value
17	Number of stacks (on the basis of one stack for two sintering belts with an area of 200 m²) - N	—	1
18	Diameter of stack orifice -D	m	6
19	Volume of gas-air mixture discharged into the atmosphere by one sintering belt - L*	m³/min	9000
20	Total volume of gas-air mixture discharged into the atmosphere - V $V = \frac{Ln}{60} = \frac{9000\cdot 2}{60}$	m³sec	300
21	Total dust emission - M_d $M_d = gV\left(1-\frac{\eta_d}{100}\right) = 2\cdot 300\left(1-\frac{90}{100}\right)$	g/sec	60
22	Emission of sulfur dioxide into the atmosphere due to the burning off of sulfur in the charge - M_{SO_2} $M^{ch}_{SO_2} = G^p \frac{10^6}{86\,400}\frac{S^{ch}}{100}\frac{\mu_{SO_2}\eta^{ch}}{\mu_S} =$ $= 0,$[illegible]$S^{ch}\eta^{ch} = 0.232\times 1.1\times 10^4\times 0.8\times 0.95$ $\mu_{SO_2} = 64$ - molecular weight of sulfur dioxide $\mu_S = 32$ - molecular weight of sulfur	g/sec	1950
23	Emission of sulfurous anhydride due to the combustion of coke oven gas - $M^c_{SO_2}$ $M^c_{SO_2} = \frac{G_{i.c}}{3600}(H_2S)^c\frac{\mu_{SO_2}}{\mu_{H_2S}} =$ $= 0,00052G_{i.c}(H_2S)^c = 0.00052\times 2300\times 5$ μ_{H_2S} - molecular weight of hydrogen sulfide	g/sec	6
24	Emission of sulfurous anhydride due to the combustion of blast furnace gas - $M^b_{SO_2}$ $M^b_{SO_2} = \frac{G_{i.b}S^b}{3600}\frac{\mu_{SO_2}}{\mu_S} =$ $= 0,00056G_{i.b}S^b = 0.00056\times 18\,900\times 0.5$	g/sec	5

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*Found from tables as a function of F_1. For T_g = 120-160°C., the following table is used:

F_1, m²	50	75	200	250/312
L, m³/min	3500	6500	9000	12 000

No.	Name, Designation, Formula and Calculation	Units	Value
25	Total emission of sulfur dioxide into the atmosphere - M_{SO_2} $M_{SO_2} = M^{ch}_{SO_2} + M^{c}_{SO_2} + M^{b}_{SO_2} = 1950 + 6 + 5$	g/sec	1960
26	Coefficient allowing for the influence of the velocity of deposition of the impurity in the atmosphere, for sulfur dioxide - F dust - F	— —	1 2
27	Exit velocity of gas-air mixture from the stack - w_0 $w_0 = \frac{4V}{\pi D^2 N} = \frac{4 \cdot 300}{\pi \cdot 6^2 \cdot 1}$	m/sec	11
	B. Calculation of Stack Height of Sintering Plant		
1	Background concentration of sulfur dioxide - $C_{b.SO_2}$ Background concentration of dust - $C_{b.d}$	mg/m^3 mg/m^3	0 0
2	Coefficient dependent on the thermal stratification of the atmosphere - A	sec$^{2/3}$ x deg $^{1/3}$	160
3	$FM_{SO_2} > FM_d$ $1 \times 1960 > 2 \times 60$ The stack height is therefore determined from the emission of sulfur dioxide	- g/sec	1960 120
4	Difference between the temperature of the gas-air mixture discharged and that of the surrounding air — ΔT $\Delta T = T_g - T_a = 150 - 30$	deg	120
5	First approximation for minimum stack height (for m = 1) - H $H = \sqrt{\frac{AM_{SO_2}Fm}{MPC}\sqrt[3]{\frac{N}{V\Delta T}}} = \sqrt{\frac{160 \times 1960 \times 1 \times 1}{0.5}\sqrt[3]{\frac{1}{300 \times 120}}}$	m	138
6	First approximation for the parameter f $f = 10^3 \frac{w_0^2 D}{H^2 \Delta T} = \frac{10^3 \times 11^2 \times 6}{138^2 \times 120}$	m/sec^2 deg	0,32

No.	Name, Designation, Formula and Calculation	Units	Value
7	First approximation for the coefficient allowing for the conditions of exit of the gas-air mixture from the stack - m	—	1,05
8	Preliminary value of the stack height - H $H = \sqrt{\frac{AM_{SO_2}Fm}{\text{MPC}}\sqrt[3]{\frac{N}{V\Delta T}}} =$ $= \sqrt{\frac{160 \times 1960 \times 1 \times 1}{0,5}\sqrt[3]{\frac{1}{300 \times 120}}}$	m	138
9	Next largest size of the height of standard stacks - H	m	150
10	Parameter f $f = 10^3 \frac{w_0^2 D}{H^2 \Delta T} = \frac{10^3 \times 11^2 \times 6}{150^2 \times 120}$ (f<6, which makes it possible to use the present Instructions)	m/sec^2 deg	0,27
11	Dimensionless coefficient allowing for the conditions of exit of the gas-air mixture from the stack - m	—	1,05
12	Maximum concentration of sulfur dioxide near the underlying surface - c_{mSO_2} $c_{m\,SO_2} = \frac{AM_{SO_2}Fm}{H^2}\sqrt[3]{\frac{N}{V\Delta T}} =$ $= \frac{160 \times 1960 \times 1 \times 1.05}{150^2}\sqrt[3]{\frac{1}{300 \times 120}}$	mg/m^3	0,44
13	Maximum concentration of dust near the underlying surface - $c_{m\,d}$ $c_{m,d} = \frac{AM_d Fm}{H^2}\sqrt[3]{\frac{N}{V\Delta T}} =$ $= \frac{160 \times 60 \times 2 \times 1.05}{150^2}\sqrt[3]{\frac{1}{300 \times 120}}$	mg/m^3	0,03
14	Distance at which the maximum concentration of noxious emissions is reached - x_m $x_m = 20H = 20 \times 150$	m	3000

Example 2

Calculation of pollution of the atmosphere with sulfur dioxide and dust discharged by a converter shop. Construction site - Central Asia.

No.	Name, Designation, Formula and Calculation	Units	Value
A.	Calculation of the amounts of sulfur dioxide and dust, volume and exit velocity of gas-air mixture discharged into the atmosphere.		
1	Number of converters in the shop	-	5
2	Capacity of a single converter	t	100
3	Number of converters operating simultaneously, including	-	3
	during the blowing of oxygen through pig - n_1	-	2
	during preheating - n_2	-	1
4	Duration of a single melting	min	45
5	Sulfur content of pig:		
	before blowing	%	0.06
	after blowing	%	0.042
6	Amount of pig produced by one converter (in 1 hr), G_1		
	$G_1 = \frac{100 \times 60}{45}$	t/hr	133
7	Duration of the period of preheating of the converter with coke oven-blast furnace gas	min	21
8	Hydrogen sulfide content of coke oven gas - $(H_2S)^c$	g/nm^3	5
9	Sulfur content of blast furnace gas - S^b	g/nm^3	0.5
10	Amount of coke oven-blast furnace gas burned in a single converter during preheating, including	nm^3	5600
	coke oven gas	nm^3	1400
	blast furnace gas	nm^3	4200
11	Concentration of dust in gas-air mixture during blowing (before purification) - g	g/m^3	30
	During preheating, dust is not discharged into the atmosphere		

No.	Name, Designation, Formula and Calculation	Units	Value
12	Type of dust-removing unit - turbulent scrubber. No sulfur removal	-	-
13	Operating value of efficiency of dust removing unit - η_d	%	98
14	Temperature of gas-air mixture discharged into the atmosphere - T_g	°C	80
15	Temperature of ambient air - T_a	°C	40
16	Number of sources of emission of noxious substances per converter - N_1	-	1
17	Diameter of orifice of emission source of noxious substances - D	m	2
18	Output of ventilation units operating near the converter (during blowing and preheating)	nm^3/hr	100,000
19	Volume of gas-air mixture discharged into the atmosphere during blowing and preheating by one converter - V_1 $V_1 = \frac{100000}{3600}\left(\frac{80}{273} + 1\right)$	m^3/sec	36
20	Emission of dust into the atmosphere by one converter during the blowing period - m_d^{bl} $M_d^{bl} = g\left(1 - \frac{\eta_d}{100}\right)V_1 = 30\left(1 - \frac{98}{100}\right)36$	g/sec	22
21	Amount of sulfur dioxide discharged by one converter during blowing - $M_{SO_2}^{bl}$ $M_{SO_2}^{bl} = \frac{100}{45}\;\frac{10^3}{60}\;\frac{(0,06 + 0,012)}{100}\;\frac{61}{32}$	g/sec	13
22	Amount of sulfur dioxide discharged into the atmosphere by one converter during preheating and formed by the combustion of coke oven-blast furnace gas - $M_{SO_2}^{bl}$ $M_{SO_2}^{pr} = \frac{1400 \times 5 \times 61}{21 \times 60 \times 31} + \frac{4200 \times 0,5 \times 61}{21 \times 60 \times 32} = 10 + 3$	g/sec	13
23	Coefficient allowing for the influence of the settling velocity of the impurity in the atmosphere, for sulfur dioxide - F dust - F	 - -	 1 2

No.	Name, Designation, Formula and Calculation	Units	Value
24	Exit velocity of gas-air mixture from aperture of emission source - w_0 $w_0 = \frac{4V_1}{\pi D^2 N_1} = \frac{4 \times 36}{3.14 \times 2^2 \times 1}$	m/sec	11
25	Shortest distance between extreme converters out of three operating ones - x_0	m	200
	Therefore in calculations for $H > 50 \div 70$ m, all the sources can be reduced to a single point		
26	The volume of gas-air mixture V_1 discharged into the atmosphere by a converter is the same during the period of blowing and preheating Therefore in the calculations one should assume $\frac{V}{N} = V_1$	m^3/sec	36
27	Total emission of sulfur dioxide into the atmosphere by all the converters - M_{SO_2} $M_{SO_2} = M^{bl}_{SO_2} n_1 + M^{pr}_{SO_2} n_2 = 13 \cdot 2 + 13 \cdot 1$	g/sec	39
28	Total discharge of dust into the atmosphere by all the converters - M_d $M_d = M^{bl} n_1 = 22 \times 2$	g/sec	44
	B. Calculation of the height of emission sources of converter shop		
1	Background concentration of sulfur dioxide - $c_{b.SO_2}$	mg/m^3	0.2
	Background concentration of dust - $c_{b.d}$	mg/m^3	0.3
2	Coefficient dependent on the thermal stratification of the atmosphere - A	$sec^{2/3} \times$ $\times deg^{1/3}$	
3	$\frac{FM_{SO_2}}{MPC_{SO_2} - c_{b.SO_2}} < \frac{FM_{п}}{MPC_d - c_{b,d}}$ $\frac{1 \times 39}{0.5 - 0.2} < \frac{2 \times 44}{0.5 - 0.3}$	mg/m^3	130 < 440
	Therefore the height of the emission source is determined from the dust emission		
4	Difference between the temperature of the gas-air mixture and that of the ambient air - ΔT $\Delta T = T_g - T_a = 80 - 40$	°C	40

No.	Name, Designation, Formula and Calculation	Units	Value
5	First approximation for minimum height of emission source (for m = 1) $H = \sqrt{\frac{AM_d Fm}{(\text{ПДК}_d - c_{b\,d})}\sqrt[3]{\frac{N}{V\Delta T}}} = \sqrt{\frac{200 \times 44 \times 2 \quad 1}{(0.5 - 0.3)}\sqrt[3]{\frac{1}{36 \times 40}}}$	m	88
6	First approximation for parameter f $f = 10^3 \frac{w_0^2 D}{H^2 \Delta T} = \frac{10^3 \times 11^2 \times 2}{88^2 \times 40}$	m/sec^2 x x deg	0.80
7	First approximation for the coefficient allowing for the conditions of exit of the gas-air mixture from the aperture of the source - m	-	0.95
8	Preliminary value for the height of emission sources - H $H = \sqrt{\frac{AM_d Fm}{(\text{ПДК}_d - c_{b\,d})}\sqrt[3]{\frac{N}{V\Delta T}}} = \sqrt{\frac{200 \times 44 \times 2 \times 0.95}{(0.5 - 0.3)}\sqrt[3]{\frac{1}{36 \times 40}}}$	m	86
9	Next largest standard height of emission source on open hearth furnaces - H	m	100
10	Parameter f $f = 10^3 \frac{w_0^2 D}{H^2 \Delta T} = \frac{10^3 \times 11^2 \times 2}{100^2 \times 40}$ ($f < 6$, which makes it possible to use the present Instructions)	m/sec^2 x x deg	0.6
11	Coefficient allowing for the conditions of exit of the gas-air mixture from the source orifice - m	-	0.95
12	Maximum concentration of dust near the underlying surface, caused by emissions of the converter shop - $c_{m.d}$ $c_{m\,d} = \frac{AM_d Fm}{H^2}\sqrt[3]{\frac{N}{V\Delta T}} = \frac{200 \times 44 \times 2 \times 0.95}{100^2}\sqrt[3]{\frac{1}{36 \times 40}}$	mg/m^3	0.15

No.	Name, Designation, Formula and Calculation	Units	Value
13	Maximum concentration of sulfur dioxide near underlying surface, caused by emissions of the converter shop - $c_{m.SO_2}$ $c_{m.SO_2} = \frac{AM_{SO_2}Fm}{H^2} \sqrt[3]{\frac{N}{V\Delta T}} = \frac{200 \times 39 \times 1 \times 0.95}{100^2} \sqrt[3]{\frac{1}{36 \times 40}}$	mg/m^3	0.07
14	Distance at which the maximum concentration of noxious emissions is reached - x_m $x_m = 20H = 20 \times 100$	m	2000
15	$c_{b.d} + c_{m.d} = 0.30 + 0.15$ $c_{b.SO_2} + c_{m.SO_2} = 0.20 + 0.07$	mg/m^3	0.45 0.27
	Calculations show that at the construction site, the concentrations of dust and sulfur dioxide will not exceed the MPC		

Example 3

Calculation of pollution of the atmosphere with sulfur dioxide discharged from stacks of the sulfuric acid shop of a sintering plant. Construction site - the Urals.

No.	Name, Designation, Formula and Calculation	Units	Value
	A. Calculation of the amount of sulfur dioxide, volume and exit velocity of gas-air mixture discharged into the atmosphere		
1	Amount of sulfuric acid produced in the shop	t/year	$3 \cdot 10^5$
2	Number of units	-	1
3	Sulfuric acid is obtained from sulfur dioxide evolved by roasting magnesium sulfite crystals $MgSO_3$		
	Magnesium sulfite is formed at sintering plant, the magnesium purification method being used to remove sulfur dioxide from the plant's emissions		
	Amount of magnesium sulfite processed (on the basis of 300 working days per year) - B	t/hr	106

No.	Name, Designation, Formula and Calculation	Units	Value
4	Sulfur content of raw material - S^P	%	19
5	Residual sulfur content of raw material subjected to roasting (roasting involves the use of natural gas containing no sulfur) - S^P_o	%	0.1
6	Content of sulfurous anhydride in the gases following roasting of the raw material - V'_{SO_2} $V'_{SO_2} = B \frac{(S^P - S^P_0)}{100} \frac{22.4 \times 10^3}{\mu_S} =$ $= 7B(S^P - S^P_0) = 7 \times 106\,(19 - 0.1),$ where μ_S is the molecular weight of sulfur	nm^3/hr	14,100
7	Sulfur dioxide losses entering the stack (in percent of total volume of sulfurous anhydride formed by roasting the raw material):		
	(a) on contact units	%	2
	(b) other process leaks	%	3
	(c) total loss - η'	%	5
8	Amount of sulfur dioxide discharged into the atmosphere - M_{SO_2} $M_{SO_2} = \frac{\eta'}{100} V'_{SO_2} \frac{\mu_{SO_2}}{22.4} \frac{10^3}{3600} =$ $= 0.00795\,\eta' V'_{SO_2} = 0.00795 \times 5 \times 14\,100,$ where μ_{SO_2} is the molecular weight of sulfur dioxide	g/sec	560
9	Temperature of gas-air mixture at exit from stack - T_g	°C	60
10	Temperature of ambient air - T_a	°C	30
11	Amount of gas-air mixture in furnace compartment (per ton of product) passing through the process units and discharged into the stack - V_g	nm^3/t	505

No.	Name, Designation, Formula and Calculation	Units	Value
12	Total amount of gas-air mixture discharged into the stack - V $V = \frac{V_g \times B}{3600}\left(\frac{T_g}{273} + 1\right) =$ $= \frac{505 \times 106}{3600}\left(\frac{60}{273} + 1\right)$	m^3/sec	18
13	Coefficient allowing for the influence of the settling velocity of the impurity in the atmosphere - F	-	1
14	Number of stacks - N	-	1
15	Diameter of stack orifice - D	m	2
16	Exit velocity of gas-air mixture from stack orifice - w_0 $w_0 = \frac{4V}{\pi D^2 N} = \frac{4 \times 18}{3.14 \times 2^2 \times 1}$	m/sec	6
B.	Calculation of stack height of sulfuric acid shop at sintering plant		
1	Background concentration of sulfur dioxide $c_{b.SO_2}$	mg/m^3	0.1
2	Coefficient dependent on the thermal stratification of the atmosphere - A	$sec^{2/3} \times$ $\times\ deg^{1/3}$	160
3	Difference in the temperatures of the gas-air mixture and air - ΔT $\Delta_T = T_g - T_a = 60-30$	°C	30
4	First approximation for minimum stack height (for m = 1) - H $H = \sqrt{\frac{AM_{SO_2}Fm}{(MPC_{SO_2} - c_{b.SO_2})}}\sqrt[3]{\frac{N}{V\Delta T}} =$ $= \sqrt{\frac{160 \times 560 \times 1 \times 1}{(0.5 - 0.1)}}\sqrt[3]{\frac{1}{18 \times 30}}$	m	166
5	First approximation for parameter f $f = 10^3 \frac{w_0^2 D}{H^2 \Delta T} = \frac{10^3 \times 6^2 \times 2}{166^2 \times 30}$	$m/sec^2 \times$ $\times$ deg	0.09
6	First approximation for the coefficient allowing for the conditions of exit of the gas-air mixture from the stack orifice - m	-	1.1

No.	Name, Designation, Formula and Calculation	Units	Value
7	Preliminary value of stack height - H $H = \sqrt{\frac{AM_{SO_2}Fm}{(MPC_{SO_2} - c_{b.SO_2})}\sqrt[3]{\frac{N}{V\Delta T}}} =$ $= \sqrt{\frac{160 \times 560 \times 1 \times 1,1}{(0,5 - 0,1)}\sqrt[3]{\frac{1}{18 \times 30}}}$	m	174
8	Next largest size of standard stacks - H	m	180
9	Parameter - f $f = 10^3 \frac{w_0^2 D}{H^2 \Delta T} = \frac{10^3 \times 6^2 \times 2}{180^2 \times 30}$ ($f < 6$, which make it possible to use the present Instructions)	m/sec^2 x x deg	0.07
10	Coefficient allowing for the conditions of exit of gas-air mixture from the stack - m	-	1.1
11	Maximum concentration of sulfur dioxide near the underlying surface - $c_{m.SO_2}$ $c_{m.SO_2} \frac{AM_{SO_2}Fm}{H^2}\sqrt[3]{\frac{N}{V\Delta T}} =$ $= \frac{160 \times 560 \times 1 \times 1,1}{180^2}\sqrt[3]{\frac{1}{18 \times 30}}$	mg/m^3	0.37
12	$c_{b.SO_2} + c_{m.SO_2} = 0.10 + 0.37$ Calculations show that at the construction site, the sulfur dioxide concentrations will not exceed the MPC	mg/m^3	0.47
13	Distance at which the maximum concentration of sulfur dioxide is reached, x_m $x_m = 20H = 20 \times 180$	m	3600

Example 4

Calculation of the amount of sulfurous anhydride and volume and exit velocity of flue gases discharged into the atmosphere during combustion of mazut in petroleum refinery installations.

No.	Name, Designation, Formula and Calculation	Units	Value
1	Unit for catalytic reforming, thermal cracking, hydrofining, atmospheric pipestill and atmospheric-vacuum pipestill, etc.	-	-
2	Type of fuel - mazut	-	-
3	Colorific value of the fuel per working mass - Q_H^p	kcal/kg	9500
4	Sulfur content of fuel - S^p	%	3.5
5	Excess air at exit from smokestack - a	-	1.4
6	Temperature of flue gases at exit from smokestack - T_g	°C	250
7	Number of stacks per installation - N_1	-	1
8	Diameter of stack orifice - D	m	5
9	Amount of fuel burned (on the basis of 330 working days per year) - B	t/hr	12.6
10	Volume of flue gases formed by the combustion of 1 kg of fuel - V_g $V_g = V_{RO_2} + V^0_{N_2} + V_{H_2O} + (\alpha - 1) V^0 = 1.62 + 11.50 + 1.90 + 0.87$	nm³/kg	15.35
11	Total volume of flue gases at exit from smokestack - V $V = \frac{V_g B \cdot 10^3}{3600}\left(\frac{T_g}{273} + 1\right) = \frac{15.35 \times 12.6 \times 10^3}{3600}\left(\frac{250}{273} + 1\right).$	m³/sec	103
12	Emission of sulfur dioxide from stack - M_{SO_2} $M_{SO_2} = \frac{B \times 10^6 \times S^p}{3600 \times 100} \cdot \frac{\mu_{SO_2}}{\mu_S} = 5.56 \times B \times S^p = 5.56 \times 12.6 \times 3.5$ where μ_{SO_2} is the molecular weight of sulfur dioxide and μ_S is the molecular weight of sulfur	g/sec	245
13	Coefficient allowing for the influence of the settling velocity of the impurity in the atmosphere - F	-	1
14	Exit velocity of flue gases from stack orifice - w_0 $w_0 = \frac{4V}{\pi D^2 N_1} = \frac{4 \times 103}{3.14 \times 5^2 \times 1}$	m/sec	5

Example 5

Calculation of the amount of sulfurous anhydride, volume and exit velocity of flue gases discharged into the atmosphere by the catalytic cracking installation of a petroleum refinery. The sulfur dioxide is formed by the combustion of mazut and burning off of the coke deposited on the catalyst.

No.	Name, Designation, Formula and Calculation	Units	Value
1	Catalytic cracking installation	-	-
2	Type of fuel - high sulfur mazut	-	-
3	Calorific value of mazut per working mass - Q^P_H	kcal/kg	9500
4	Sulfur content of mazut - S^p_m	%	4
5	Excess air during the combustion of mazut in furnaces - α^m	-	1.4
6	Amount of mazut burned (based on 330 working days per year) - B^m	t/hr	1.3
7	Sulfur content of coke - S^P_c	%	5.5
8	Excess air during burning of coke - α_c	-	1.02
9	Amount of burned coke - B^c	t/hr	11
10	Temperature of gas-air mixture at exit from stack - T_g	°C	250
11	Number of stacks - N	-	1
12	Volume of gas-air mixture formed by the combustion of 1 kg of mazut - V^m_g $V^m_g = V_{RO_2} + V^0_{N_2} + V_{H_2O} + (\alpha - 1)V^0 = 1.62 + 11.6 + 1.99 + 0.82$	nm^3/kg	16
13	Volume of gas-air mixture formed by the combustion of mazut - V^m $V^m = V^m_g B^m \frac{1000}{3600}\left(\frac{T_r}{273} + 1\right) = 16.0 \times 1.3 \frac{1000}{3600}\left(\frac{250}{273} + 1\right)$	m^3/sec	11.2
14	Amount of sulfur dioxide formed by the combustion of mazut - $M^m_{SO_2}$ $M^m_{SO_2} = 5.56 \times B^m \times S^P_m = 5.56 \times 1.3 \times 4$	g/sec	29

No.	Name, Designation, Formula and Calculation	Units	Value
15	Volume of gas-air mixture formed by the combustion of 1 kilogram of coke, V_g^c $V_g^c = V_{RO_2} + V_{N_2}^0 + V_{H_2O} + (\alpha^c - 1)V^0 =$ $= 1.63 + 7.17 + 1.01 + (1.02 - 1)\,9.08$	nm^3/kg	10
16	Volume of gas-air mixture formed by the combustion of coke - V^c $V^c = V_g^c B^c \frac{1000}{3600}\left(\frac{T_g}{273} + 1\right) =$ $= 10 \times 11 \times \frac{1000}{3600}\left(\frac{250}{273} + 1\right)$	m^3/sec	58.5
17	Amount of sulfur dioxide formed by the combustion of coke - $M_{SO_2}^c$ $M_{SO_2}^c = 5.56 \times B^c S_c^p = 5.56 \times 11 \times 5.5$	g/sec	336
18	Total volume of gas-air mixture discharged into the stack - V $V = V^m + V^c = 11.2 + 58.5$	m^3/sec	69.7
19	Total amount of sulfur dioxide discharged into the stack - M_{SO_2} $M_{SO_2} = M_{SO_2}^m + M_{SO_2}^c = 29 + 336$	t/sec	365
20	Coefficient allowing for the influence of the settling velocity of the impurity in the atmosphere - F	-	1
21	Stack Height - H	m	100
22	Diameter of stack orifice - D	m	2.5
23	Exit velocity of gas-air mixture from stack orifice - w_0 $w_0 = \frac{4V}{\pi D^2 N} = \frac{4 \times 69.7}{3.14 \times 2.5^2 \times 1}$	m/sec	14.3
24	Temperature of ambient air - T_a	deg	25
25	Parameter f $f = 10^3 \frac{w_0^2 D}{H^2 \Delta T} = \frac{10^3 \times (11.3)^2 \times 2.5}{100^2 (250 - 25)}$ ($f < 6$, which makes it possible to use the present Instructions)	m/sec^2 deg	0.23

Example 6

Calculation of pollution of the atmosphere with sulfur dioxide from an operating petroleum refinery. Location - Central Asia.

No.	Number of Sources	Name, Designation, Formula and Calculation	Units	Value
		A. Calculation of ground concentrations of sulfur dioxide		
1	-	Background concentration of sulfur dioxide - $c_b.SO_2$	mg/m^3	0
2	-	Coefficient dependent on the thermal stratification of the atmosphere - A	$sec^{2/3}$ X X $deg^{1/3}$	200
3	-	Coefficient allowing for the settling of the impurity - F	-	1
4	-	Temperature of ambient air - T_a	°C	40
5		Type of installations:		
	1	Catalytic reforming installation	-	-
	2	Thermal cracking installation	-	-
	3	Hydrofining installation	-	-
	4	Atmospheric vacuum pipe still	-	-
	5	Installation for producing elemental sulfur from hydrogen sulfide gas	-	-
6	1-5	Number of stacks per installation	-	1
7	1-5	Stack height - H	m	100
8	1-5	Diameter of stack orifice - D	m	2
9		Temperature of gas-air mixture at exit from stack - T_g	°C	
	1			400
	2			450
	3			250
	4			500
	5			500
10		Volume of gas-air mixture discharged from the stack - V_1	m^3/sec	
	1			50
	2			100
	3			30
	4			80
	5			35

No.	Number of Sources	Name, Designation, Formula and Calculation	Units	Value
11		Amount of sulfur dioxide discharged into the atmosphere - M_{SO_2}	g/sec	
	1			200
	2			250
	3			150
	4			180
	5			300
12		Exit velocity of gas-air mixture from stack orifice - w_0		
		$w_0 = \frac{4V_1}{\pi D^2 N_1}$	m/sec	
	1	$w_0 = \frac{4 \times 50}{\pi \times 2^2 \times 1}$		16
	2	$w_0 = \frac{4 \times 100}{\pi \times 2^2 \times 1}$		32
	3	$w_0 = \frac{4 \times 30}{\pi \times 2^2 \times 1}$		10
	4	$w_0 = \frac{4 \times 80}{\pi \times 2^2 \times 1}$		25
	5	$w_0 = \frac{4 \times 35}{\pi \times 2^2 \times 1}$		11
13		Difference in the temperatures of the gas-air mixture and ambient air - ΔT		
		$\Delta T = T_g - T_a$	deg	
	1	$\Delta T = 400 - 40$		360
	2	$\Delta T = 450 - 40$		410
	3	$\Delta T = 250 - 40$		210
	4	$\Delta T = 500 - 40$		460
	5	$\Delta T = 500 - 40$		460
14		Parameter f		
		$f = 10^3 \frac{w_0^2 D}{H^2 \Delta T}$	m/sec² deg	
	1	$f = \frac{10^3 \times 16^2 \times 2}{100^2 \times 360}$		0.14
	2	$f = \frac{10^3 \times 32^2 \times 2}{100^2 \times 410}$		0.50
	3	$f = \frac{10^3 \times 10^2 \times 2}{100^2 \times 210}$		0.10

No.	Number of Sources	Name, Designation, Formula and Calculation	Units	Value
14	4	$f = \frac{10^3 \times 25^2 \times 2}{100^2 \times 450}$		0.27
	5	$f = \frac{10^3 \times 11^2 \times 2}{100^2 \times 400}$		0.05
		(For all sources $f < 6$, which makes it possible to use the present Instructions)		
15		Coefficient allowing for the conditions of exit of flue gases from stack orifice - m		
	1		—	1.1
	2		—	1.0
	3		—	1.0
	4		—	1.05
	5		—	1.1
16		Maximum concentration of sulfur dioxide - $c_{m.SO_2}$		
		$c_{m.SO_2} = \frac{AM_{SO_2}Fm}{H^2} \sqrt[3]{\frac{N}{V \Delta T}}$	mg/m^3	
	1	$c_{m1} = \frac{200 \times 200 \times 1 \times 1.1}{100^2} \sqrt[3]{\frac{1}{50 \times 360}}$		0.17
	2	$c_{m2} = \frac{200 \times 250 \times 1 \times 1}{100^2} \sqrt[3]{\frac{1}{100 \times 410}}$		0.14
	3	$c_{m3} = \frac{200 \times 150 \times 1 \times 1.1}{100^2} \sqrt[3]{\frac{1}{30 \times 210}}$		0.18
	4	$c_{m4} = \frac{200 \times 180 \times 1 \times 1.05}{100^2} \sqrt[3]{\frac{1}{80 \times 460}}$		0.11
	5	$c_{m5} = \frac{200 \times 300 \times 1 \times 1.1}{100^2} \sqrt[3]{\frac{1}{35 \times 460}}$		0.26
		$c_{m1} + c_{m2} + c_{m3} + c_{m4} + c_{m5} =$ $= 0.17 + 0.14 + 0.18 + 0.11 + 0.26$		0.86
17	1 - 5	Distance from stack where the maximum concentration x_m is observed at the unsafe wind velocity		
		$x_m = 20H = 20 \times 100$	m	2000

No.	Number of Sources	Name, Designation, Formula and Calculation	Units	Value
18		Unsafe velocity u_m		
		$u_m \simeq 0.65 \sqrt[3]{\frac{V_1 \Delta T}{N_1 H}}$	m/sec	
	1	$u_{m1} \simeq 0.65 \sqrt[3]{\frac{50 \times 360}{1 \times 100}}$		3.7
	2	$u_{m2} \simeq 0.65 \sqrt[3]{\frac{100 \times 410}{1 \times 100}}$		4.8
	3	$u_{m3} \simeq 0.35 \sqrt[3]{\frac{30 \times 210}{1 \times 100}}$		2.6
	4	$u_{m4} \simeq 0.65 \sqrt[3]{\frac{80 \times 460}{1 \times 100}}$		4,6
	5	$u_{m5} \simeq 0.65 \sqrt[3]{\frac{35 \times 460}{1 \times 100}}$		3.5
19		Weighted mean value of unsafe wind velocity u_{mav} for the given set of sources		
		$u_{mav} = \frac{u_{m1}c_{m1} + u_{m2}c_{m2} + u_{m3}c_{m3} + u_{m4}c_{m4} + u_{m5}c_{m5}}{c_{m1} + c_{m2} + c_{m3} + c_{m4} + c_{m5}} = \frac{3.7 \times 0.17 + 4.8 \times 0.14 + 2.6 \times 0.18 + 4.6 \times 0.11 + 3.5 \times 0.26}{0.86}$	mg/m^3	3.7
20		Value of the ratio $\frac{u_{mav}}{u_m}$		
	1	$\frac{u_{mav}}{u_{m1}} = \frac{3.7}{3.7}$	-	1.0
	2	$\frac{u_{mav}}{u_{m2}} = \frac{3.7}{4.8}$	-	0.77
	3	$\frac{u_{mav}}{u_{m3}} = \frac{3.7}{2.6}$	-	1.42
	4	$\frac{u_{mav}}{u_{m4}} = \frac{3.7}{4.6}$	-	0.80
	5	$\frac{u_{mav}}{u_{m5}} = \frac{3.7}{3.5}$	-	1.06

No.	Number of Sources	Name, Designation, Formula and Calculation	Units	Value
21		Maximum concentration of sulfur dioxide c_{mu} (for $u = u_{mav}$)		
		$c_{mu} = rc_m$	mg/m^3	
	1	$c_{mu_1} = 1.0 \times 0.17$		0.17
	2	$c_{mu_2} = 0.91 \times 0.14$		0.13
	3	$c_{mu_3} = 0.90 \times 0.18$		0.16
	4	$c_{mu_4} = 0.93 \times 0.11$		0.10
	5	$c_{mu_5} = 1.0 \times 0.26$		0.26
		$c_{mu_1} + c_{mu_2} + c_{mu_3} + c_{mu_4} + c_{mu_5} =$ $= 0.17 + 0.13 + 0.16 + 0.10 + 0.26 =$ $= 0.82 >$ MPC		
22		Distance at which the maximum concentration of sulfur dioxide x_{mu} is observed for $u = u_{mav}$		
		$x_{mu} = px_m$	m	
	1	$x_{mu_1} = 1.0 \times 2000$		2000
	2	$x_{mu_2} = 1.22 \times 2000$		2400
	3	$x_{mu_3} = 0.87 \times 2000$		1700
	4	$x_{mu_4} = 1.18 \times 2000$		2400
	5	$x_{mu_5} = 1.0 \times 2000$		2000
23	1 - 5	The distance between extreme sources does not exceed 300-400 m (3-4H), so that they can be assumed to be located at a single point. The graphical determination of total concentration c at different distances x is illustrated in Fig. 8.		

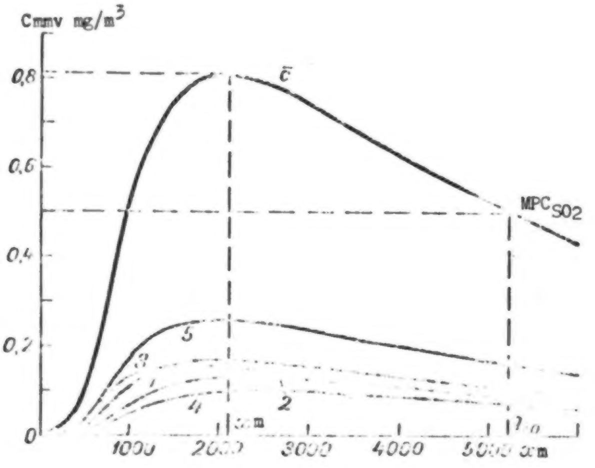

Fig. 8. Example of calculation of maximum ground concentration of sulfur dioxide from five closely grouped installations of a petroleum refinery.

No.	Number of Sources	Name, Designation, Formula and Calculation	Units	Value
24	1 - 5	Maximum concentration from the set or sources - c_m It is therefore necessary to increase the stack height or set up a sanitary-protective zone	mg/m^3	0,81
25	1 - 5	Distance at which the maximum concentration x_m is observed	m	2100
26	1 - 5	Distance up to which the total concentration exceeds the MPC - L_0 Sources located close to each other, and therefore L_0 is the same in all directions.	m	5000

B. Calculation of Sanitary Protective Zone Measured from an Operating Petroleum Refinery

1. Minimum dimension of the sanitary-protective zone (according to "Sanitary Norms for Planning Industrial Enterprises" ℓ_o=1000 m.

2. Distance L_0 up to which sulfur dioxide concentrations exceeding the MPC are observed, 5000 m (see Fig. 8).

3. The mean annual frequency of wind of different directions (according to the climatic handbook) p and length of sanitary-protective zone l are given in the table:

	N	NE	E	SE	S	SW	W	NW
p %	8	7	5	11	14	19	29	7
l km	5	5	5	5	5,5	7,5	11,5	5
$l = \begin{cases} L_0 \cdot \frac{p}{p_0} & \text{for } p > p_0 \\ L_0 & \text{for } p < p_0 \end{cases}$								

4. Figure 9 shows the boundaries of the sanitary-protective zone.

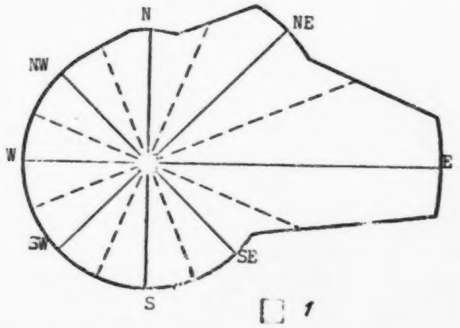

Fig. 9. Example of calculation of boundaries of sanitary protective zone of petroleum refinery (1).